Technical Report HL-95-13
March 1996

**US Army Corps of Engineers**
Waterways Experiment Station

# Redeye Crossing Reach, Lower Mississippi River

## Report 2
## Navigation Conditions

*by* *Randy A. McCollum, Michelle Thevenot*





Prepared for U.S. Army Engineer District, New Orleans

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U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
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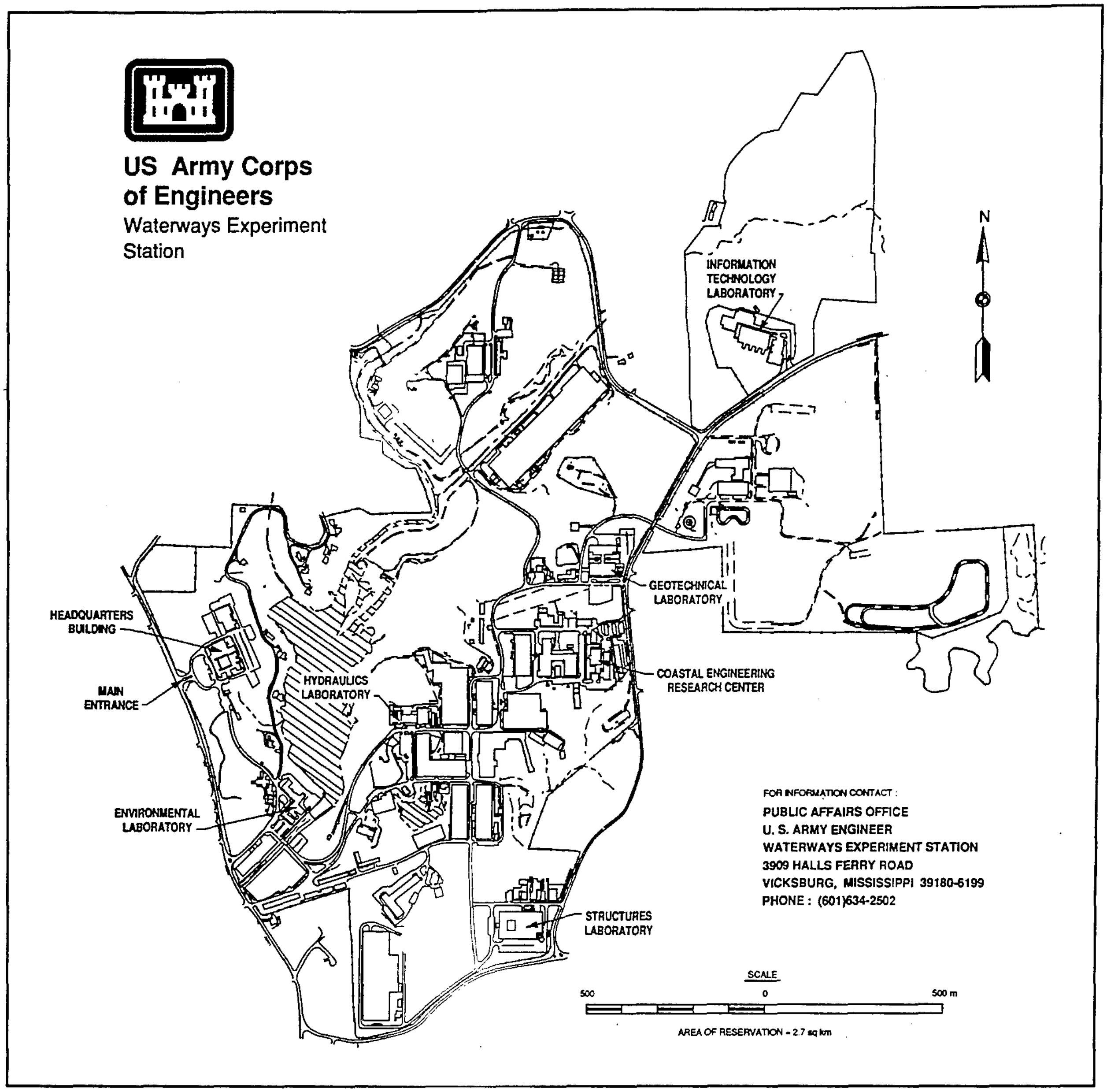
Report 2 of a series



Prepared for U.S. Army Engineer District, New Orleans
New Orleans, LA 70160-0267




**Waterways Experiment Station Cataloging-in-Publication Data**

McCollum, Randy A.

Redeye Crossing Reach, Lower Mississippi River. Report 2, Navigation conditions / by Randy A. McCollum, Michelle Thevenot ; prepared for U.S. Army Engineer District, New Orleans.

188 p. : ill. ; 28 cm. -- (Technical report ; HL-95-13 rept.2)

Includes bibliographical references.

Report 2 of a series.

1. Mississippi River. 2. Dikes (Engineering) -- Mississippi River. 3. Navigation -- Mississippi River. 4. Redeye Crossing Reach (La.) I. Thevenot, Michelle. II. United States. Army. Corps of Engineers. New Orleans District. III. U.S. Army Engineer Waterways Experiment Station. IV. Hydraulics Laboratory (U.S. Army Engineer Waterways Experiment Station) V. Title. V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; HL-95-13 rept.2.

TA7 W34 no.HL-95-13 rept.2

# Contents

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# Preface

The ship/tow simulator investigation of the Redeye Crossing Reach of the Mississippi River near Baton Rouge, LA, as documented in this report, was performed for the U.S. Army Engineer District, New Orleans. This is Report 2 of a series. Report 1 discusses the physical and numerical sedimentation studies and the hydrodynamic modeling of currents used in the navigation studies.

Ms. Nancy Powell was the liason for the Engineering Division, New Orleans District, during the study.

The investigation was conducted in the Hydraulics Laboratory (HL) of the U.S. Army Engineer Waterways Experiment Station (WES) from January through November 1991 under the direction of Messrs. Frank A. Herrmann, Jr., Director, HL (retired); Richard A. Sager, Assistant Director, HL; Marden B. Boyd, Chief, Waterways Division (WD) (retired), HL; and Dr. L. L. Daggett, Chief, Navigation Branch (NB), WD. The study was performed by Ms. Michelle Thevenot and Mr. Randy A. McCollum, NB. Ms. Donna C. Derrick, NB, provided assistance in preparation of the visual scene databases. This report was prepared by Mr. McCollum and Ms. Thevenot.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

# Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| cubic feet | 0.02831685 | cubic meters |
| cubic yards | 0.7645549 | cubic meters |
| degrees (angle) | 0.01745329 | radians |
| feet | 0.3048 | meters |
| horsepower (550 foot-pounds (force) per second) | 745.6999 | watts |
| miles (U.S. statute) | 1.609344 | kilometers |

# 1 Introduction

## Description of Problem

Redeye Crossing is located on the lower Mississippi River between River Miles 223 and 225 Above Head of Passes (AHP) about 3 miles[1] downstream of the I-10 Highway bridge at Baton Rouge, LA (Figure 1). Traffic on this section of river consists of tows from 1 to 49 barges powered by towboats from 800 to over 10,000 hp. Oceangoing vessels with drafts up to 40 ft use the deepwater channel. The present channel requires approximately 3 million cubic yards of dredging annually to maintain the 40-ft deep-draft navigation channel through the crossing. The proposed 45-ft deep-draft navigation channel would require increased maintenance dredging. Several studies have shown that dredging can be reduced by altering the hydrodynamics of a system through strategically implementing training structures.

Typically, the stage at Redeye Crossing varies over a range of about 30 ft during a water year. Average water velocities in the crossing range from about 3 fps during low-water stages to about 6 fps during high-water stages. Without maintenance dredging, the controlling depths at the crossing would be less than 30 ft during low-water periods. The U.S. Army Engineer District, New Orleans, has proposed building dikes at Redeye Crossing to reduce maintenance dredging while increasing the ship draft at the Port of Baton Rouge.

## Purpose of Study

The purpose of the Redeye Crossing Reach navigation study was to evaluate the effects of the proposed training structures on normal tow and ship traffic. The Mississippi River system at Redeye Crossing was analyzed to determine if the proposed training structures would be a navigation hazard to ships using the deep-water channel and if the resulting increase of current speed and reduction of available channel would seriously impact the small and

[1] A table of factors for converting non-SI units of measurement to SI units is found on page vii.

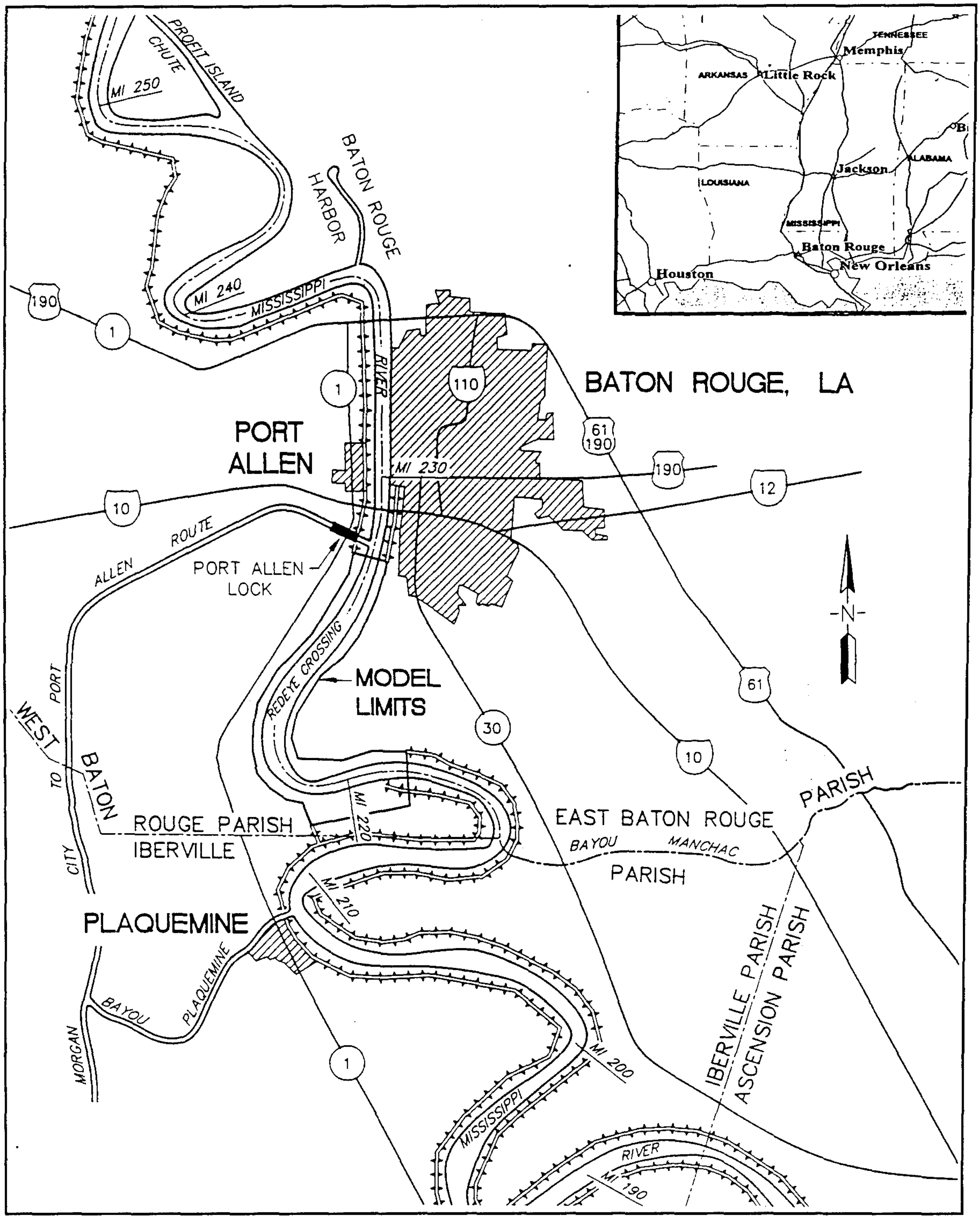


Figure 1. Vicinity map

large tows traversing the reach. Report 1[1] discusses the physical and numerical sedimentation studies along with the hydrodynamic modeling of currents used in the navigation studies.

## Scope of Report

This report describes the purpose, background, approach, results, and conclusions and recommendations of the navigation study. It covers the three primary classes of water transportation on this reach of the river that would be affected by the proposed training structures.

Chapter 1 provides background information pertinent to all parts of the study.

The next three chapters cover each of the major study categories:

*a.* Deep-draft ships.

*b.* Small tows (1, 2, or 4 barges).

*c.* Large tows (25 or 49 barges).

Chapter 5 will discuss general conclusions and recommendations based on the three studies.

## Data Development

In order to simulate the study area, it is necessary to develop information relative to five types of input data:

*a.* *The channel database* contains dimensions for the existing channel and the proposed channel modifications. It defines the channel cross sections, bank slope angle, overbank depth, initial conditions, and autopilot track-line and speed definition.

*b.* *The visual scene database* is composed of three-dimensional images of principal features of the simulated area, including the land, water, aids to navigation, docks, buildings, etc.

*c.* *The radar database* contains the features for the plan view of the study area of objects that would be displayed on a vessel's radar.

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[1] T. J. Pokrefke, C. R. Nickles, N. K. Raphelt, M. J. Trawle, and M. B. Boyd. (1995). "Redeye Crossing Reach, Lower Mississippi River; Report 1, Sediment Investigation," Technical Report HL-95-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

*d.* *The ship data file* defines the characteristics and hydrodynamic coefficients for the test vessels.

*e.* The current pattern in the channel is defined in the *current database* and includes the magnitude and direction of the current and the water depth for each cross section defined in the channel database.

## Channel

Channel cross sections are used to define the ship simulator channel database. The existing channel database was developed from District-furnished hydrographic survey charts of December 1986. This was the most recent information available concerning depths, dimensions, and bank lines of the channel. State planar coordinates as shown on the survey were used for the definition of the data. Prototype survey ranges were used to locate the simulator cross sections when possible. If the prototype survey ranges were not spaced closely enough for simulator purposes, a new range was interpolated. The plan condition databases were developed from data generated by the TABS model of the plan.[1]

The ship simulator model uses eight equally spaced points to define each cross section. At each of these points, a water depth is required. For each cross section, the location, width, right and left bank slopes, and overbank depths are required. The channel depths at each of the eight points were obtained from the TABS-MD model study[1] for numerical model analysis of sedimentation conducted prior to the simulation studies.

The channel side slope and overbank depths are used to calculate bank force and moment. The shallower the overbank and the steeper the side slope, the greater the computed bank force and moment. A small difference (1 to 2 ft) in channel bottom and overbank depth produces negligible bank forces and moments.

## Visual Scene

The visual scene database was created from the same maps noted in the discussion of the channel and topographic maps. As in the development of the channel database, the state planar coordinate system was used. Photographs provided by the District, photographs made during an inspection trip prior to initiating the study, and pilots' comments made during the inspection trip constituted the other sources of information for the scene. These allowed inclusion of the significant physical features and also helped determine which,

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[1] T. J. Pokrefke, C. R. Nickles, N. K. Raphelt, M. J. Trawle, and M. B. Boyd. (1995). "Redeye Crossing Reach, Lower Mississippi River; Report 1, Sediment Investigation," Technical Report HL-95-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

if any, features the pilots use for referencing their position and motion. All aids to navigation such as buoys, ship navigation ranges, buildings, docks, docked vessels, transmission towers, and any other significant landmarks were included in the visual scene. The visual scene also included the traffic vessel (ship or tow) that was used for each test scenario.

The visual scene is generated in three dimensions: north-south, east-west, and vertical elevation. As the test vessel (ship or tow) progresses through the channel, the three-dimensional picture is constantly transformed into a two-dimensional perspective graphic image representing the relative size of the objects in the scene as a function of the vessel's position and orientation and the relative direction and position from the perspective of the pilot on the bridge for viewing. The image is produced by a graphics projector that projects to a screen in front of the pilot and console to replicate what a pilot would see directly out the front window of the bridge. The graphics hardware used for the project consisted of two stand-alone computers (Silicon Graphics Iris 2300 and Iris 2400) connected with the main computer to obtain information for updating the viewing position and orientation. This information includes parameters such as vessel heading, rate of turn, forward and lateral velocity, and position. Also, the viewing angle is passed to the graphic computers for the look-around feature on the simulator console, which encompasses only a 40-degree field of view. This feature simulates the pilot's ability to see any object with a turn of his head. The pilot's position on the bridge can also be changed from the center of the bridge to any position wing to wing to simulate the pilot walking across the bridge to obtain a better view, e.g., along the edge of the ship from the bridge wing. The use of two graphic computers allows two independent views. These two views enable the pilot to keep the "straight ahead" view on the projection screen and allow him to "look back" at an overtaking or passing traffic vessel on a computer monitor without constantly changing the look-around angle on the projected image.

### Radar

The radar database is used by the radar software to create a simulated radar image for use by the test pilots. The radar database contains x- and y-coordinates that define the border between land and water. The file also contains coordinates for any structure on the bank or in the water such as docks, other vessels, or aids to navigation. In short, these data basically define what a pilot would see on a shipboard radar. The radar image is a continuously updated plan view of the vessel's position relative to the surrounding area. Three different ranges of 0.5, 1.0, and 2.0 miles were programmed to enable the pilot to choose the scale needed.

### Currents

A current database contains current magnitude and direction at eight points across the channel at each of the cross sections defined in the channel.

Channel bottom depths are also given at each of these eight points and are included in the channel definition. Interpolation of the data between cross sections provides continuous and smooth current patterns at any position in the simulated scene.

Detailed currents for the existing channel and the proposed channel modifications were provided by a TABS-MD numerical model[1] performed in conjunction with the numerical sedimentation study. The resulting changes in the channel bed form due to use of channel contraction works in the proposed channel modifications were computed by the TABS sedimentation model (STUDH); then the resultant channel bed was used to compute currents in the proposed modified channels using the TABS hydrodynamic model.

### Wind

The dominant wind was determined by talking with the local pilots who operate in the test area. For this study, winds were not determined to be a major factor for any of the test vessels; therefore, no wind effect was established for the simulation scenarios.

### Ships

The ship model used in this study was developed for WES by Tracor Hydronautics, Inc., Laurel, MD. The models for the 2-barge and 25-barge tow configurations were also developed by Tracor Hydronautics, Inc.[2,3]

The model for the 49-barge tow configuration was developed for this study by BMT International, Inc., Columbia, MD.[4]

Testing was performed on the U.S. Army Engineer Waterways Experiment Station (WES) ship simulator. The ship simulator provides a console for the ship helm. The pilot has the ship's wheel, engine control, revolutions per

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[1] T. J. Pokrefke, C. R. Nickles, N. K. Raphelt, M. J. Trawle, and M. B. Boyd. (1995). "Redeye Crossing Reach, Lower Mississippi River; Report 1, Sediment Investigation," Technical Report HL-95-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[2] V. Ankudinov. (1990). "Hydrodynamic and mathematical models for ship maneuvering simulations of three tow configurations in deep water and restricted water depth conditions," Prepared for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, by Tracor Hydronautics, Laurel, MD.

[3] V. Ankudinov. (1989). "Analyses of model tests and maneuvering predictions for 6, 15, and 25 barge river tows," Performed for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, by Tracor Hydronautics, Laurel, MD.

[4] V. K. Ankudinov. (1991). "Hydrodynamic and mathematical model for ship maneuvering simulations of a 49 barge tow with triple propellers in support of WES for Lower Mississippi Crossing navigation study," Prepared for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, by BMT International, Inc., Columbia, MD.

minute (rpm) indicator, rudder position, rudder command, and rate of turn indicator on this console. The visual image is provided on a projected screen ahead of the pilot. The radar image is provided on one computer monitor and another monitor provides the precision navigation parameters of Doppler speed through the water, speed across the bottom, lateral speed and direction of the bow and stern, wind speed and direction, and heading.

# 2 Navigation Study, Deep-Draft Ships

Formal pilot testing was performed with six professional ship pilots licensed to operate in the Redeye Crossing Reach. Involving the local professional ship pilots incorporated their experience and familiarity with handling ships in the study area in the project navigation evaluation.

## Validation

The simulation was validated over a 5-day period with the assistance of two pilots who were licensed to operate this reach and who were thoroughly familiar with this segment of the river. The following information was verified and fine tuned during validation:

*a.* The channel definition.

(1) Bank conditions.

(2) Currents.

*b.* The visual scene and radar image of the study area.

(1) Location of all aids to navigation.

(2) Location and orientation of moored barges.

(3) Location of buildings, towers, etc., that would be visible from the vessel.

The design ship had been validated and used in previous simulations at WES.

To validate the reaction of the vessel to bank forces, several simulation runs were made with the vessel transiting the entire study area. Special attention was given by the pilots to the response of the ship to the bank forces. Problem areas were isolated, and the prototype data for these areas were

examined. The values for the overbank depth, the side slope, or the bank force coefficient were then adjusted. Simulation runs were then undertaken through the problem areas, and if necessary, further adjustment was made. This process was repeated until the pilot was satisfied that the simulated vessel response to the bank force was similar to that of an actual vessel passing through the same reach in the prototype.

The reaction of the vessel to current forces was verified by conducting several simulation runs over the entire study area. The pilot was instructed to pay special attention to the current effects. The validation pilots were satisfied that the vessel response to each of the current conditions was similar to responses they had experienced in real-life operation in the prototype.

The visual scene and radar image of the study area were checked during validation of the other parameters. If the pilots noticed something missing or misplaced, this was checked against prototype information and corrected.

## Test Conditions

The plans tested in the simulation were derived from the numerical and physical model studies. The plans tested were as follows:

*a.* Existing condition, 38-ft-draft ship.

*b.* Plan 5A Optimized: six-dike plan to maintain a 40-ft navigation channel, 38-ft-draft ship.

*c.* Plan 8A Optimized: six-dike plan to maintain a 45-ft navigation channel, 43-ft-draft ship.

The current conditions used to test the three plan conditions were based on stage height above mean low water (mlw) at the Baton Rouge gauge. The river discharges and corresponding stages used for testing are as follows:

*a.* 228,000 cfs, 7-ft stage.

*b.* 450,000 cfs, 17-ft stage.

*c.* 530,000 cfs, 20-ft stage.

*d.* 1,500,000 cfs, 43-ft stage.

Two intermediate discharge flows were used, based on which plan was being tested. The critical intermediate flow was established to be the minimum stage at which tow traffic would still be forced to stay within the deep-water channel and could not pass over the point bar. At this time in the study, a decision was made that tows would not be allowed to go over the proposed dikes. The minimum depth criterion being considered if passage over the

dikes was to be allowed was set at 12 ft. For Plan 5A Optimized at the time of the ship tests, the maximum dike elevation was +5 ft; therefore, a 17-ft stage (450,000 cfs) was the minimum before tow traffic might be allowed to pass over the dikes. Likewise, Plan 8A Optimized was tested at a minimum 20-ft stage (530,000 cfs), yielding a slightly higher clearance of 13 ft before tows could pass over the dikes. Current vector plots for the existing condition are presented in Plates 1-4, Plan 5A in Plates 5-7, and Plan 8A in Plates 8-10.

For each run, a traffic tow was encountered. This tow was an autopiloted vessel, running on a predetermined track at a controlled speed. The pilot of the ship was responsible for avoiding the tow, since the "ghost" tow was on autopilot and could not perform any avoidance maneuvers. The ship was always traveling in the opposite direction of the ghost tow so that a meeting situation occurred.

The testing schedule as implemented on the WES ship simulator for the ship is summarized in the following tabulation.

The test condition to be run was chosen at random. The chosen condition was then tested and removed from the list of conditions. This was done to prevent prejudicing the results as would happen if, for example, all existing conditions were run prior to running the plans. Practice with the simulation on any given plan or test condition could bias the results, making that plan or condition appear easier to perform than another plan or condition with which the pilot was less familiar.

During each run, the characteristic parameters of the ship were automatically recorded every 5 seconds. These parameters included the position of the ship's center of gravity, speed, rpm of the engine, heading, drift angle, rate of turn, rudder angle, and port and starboard clearances.

The simulator tests were evaluated based on pilot ratings and comments, ship tracks, and statistical analysis of various ship control parameters recorded during testing. An additional parameter, minimum distance between vessels, was determined in a postanalysis of test data and included as a indication of safe passing conditions. The following section will present these four methods of analysis.

## Study Results

### Final questionnaire

After finishing all test runs, the pilots completed a final questionnaire to give their opinions on the project as well as on the simulation. Some of the

| Plan | River Discharge cfs | Direction |
|---|---|---|
| Existing | 228,000 | Upstream |
| | | Downstream |
| | 450,000 | Upstream |
| | | Downstream |
| | 530,000 | Upstream |
| | | Downstream |
| | 1,500,000 | Upstream |
| | | Downstream |
| 5A Optimized | 228,000 | Upstream |
| | | Downstream |
| | 450,000 | Upstream |
| | | Downstream |
| | 1,500,000 | Upstream |
| | | Downstream |
| 8A Optimized | 228,000 | Upstream |
| | | Downstream |
| | 530,000 | Upstream |
| | | Downstream |
| | 1,500,000 | Upstream |
| | | Downstream |

comments made by the pilots on the project follow:

**1. How will the proposed dikes affect safety at Redeye Crossing?**

"Redeye Crossing should have a more stable shoal area giving the Corps and pilots a better idea of how they can run a ship at different drafts and different gauges."

"I feel the dikes will reduce the usable area of river, therefore, reduce safety."

"I believe it could become very dangerous and could possibly cause severe accidents at Dow Missouri Bend Dock. Another concern - an oil tanker hitting the dike, causing major oil pollution."

"There will have to be one-way traffic at the dikes."

**2. How will ship and barge traffic be affected by the proposed dikes?**

"They will be forced to meet much closer than without dikes."
"It will become a channel confined to one-way passage. Slow-moving upbound traffic may come to a slow crawl, thus tying this channel up for a great amount of time for southbound traffic waiting to pass the crossing."
"It would make the current stronger causing tows and ships to handle very poorly."
"Northbound traffic somewhat slower, traffic should still be able to stay out of southbound traffic lanes."

**3. Do you have any suggestions for changing the dike location or alignment that would improve navigation?**

"No."
"None."
"If it must be put in for experimental reasons, I would locate the dike at Bayou Goula Bend, due to the dock at Missouri Bend."

**4. Do you have any suggestions for improving the simulation?**

"None that I know of."
"No, unless traffic could be used."
"The simulation is very close to real ship handling."
"The tow programmed into the simulator was not handling like a normal tow would handle."

**5. On a scale of 0 to 10, what is your overall opinion of the simulator and of the Redeye Crossing simulation?**

"3"
"7 - It would be an impossibility to simulate the accurate characteristics of handling a ship by a machine."
"9"
"10"
"I would give the simulator a very high rating of about 9."
"10"

**6. Comments?**

"I am concerned that the proposed dike system might cause accidents, oil pollution, and death."
"The dikes should be installed! 1 - It would have less effect on pilots. 2 - Make Redeye Crossing easier to run. 3 - Less stress on pilots (not having to worry about draft restrictions). The dikes should not present a problem and I believe that it may make that area safer to transit: any loss of power or steering could be just as bad without the dikes."

"I think the overall amount of money saved from dredging by the dikes would not be worth the headaches caused by the traffic congestion created in this crossing...."
"No dikes!"

### Pilot ratings

After each individual run, the test pilot was asked to rate several questions pertaining to the run he had just completed on a scale of 0 to 10. The ratings of all six pilots for each run condition were averaged and plotted in bar chart form to allow direct comparison of the pilots' perception of each plan condition in relation to the other plan conditions. The questions asked concerned the following factors:

*a.* Difficulty of run (DIFF.).

*b.* Current effect on ship (CURRENT).

*c.* Amount of attention required (ATTN).

*d.* Danger of grounding or striking object (DANGER).

*e.* Realism of simulator (REAL. SIM.).

*f.* Realism of current (REAL. CUR.).

**Upstream runs, 228,000-cfs flow**. For all questions, the pilots rated Plan 5A about the same as or lower than the existing condition (Figure 2). The largest difference of rating was for danger of grounding or striking an object where the plan condition was actually rated considerably lower than the existing condition. Plan 8A was rated as almost the same or slightly higher for all questions than the existing condition, except for attention required, where it was rated slightly lower than the existing condition.

**Downstream runs, 228,000-cfs flow**. The ratings for this flow condition (Figure 3) show that the pilots rated the two plan channels slightly lower than the existing channels for all but current effect and simulator realism. Difficulty of run, danger of grounding or striking an object, and attention required were rated lower for the plan channels (considerably lower for Plan 5A) than the existing condition, even though the current effect was rated considerably higher for the plan channels than the existing.

**Upstream runs, 450,000-cfs flow**. Difficulty of run, attention required, danger of striking an object, and simulator realism were rated almost equally or slightly lower for Plan 5A than the existing condition (Figure 4). Current effects and current realism were rated higher for Plan 5A than the existing condition.

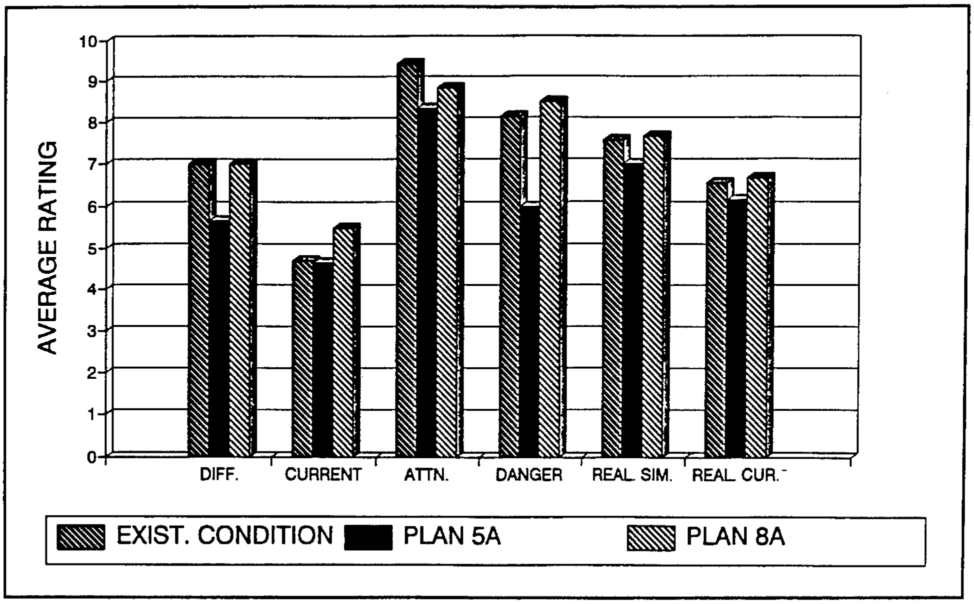



Figure 2. Ship pilot ratings, 228,000-cfs flow, upstream runs

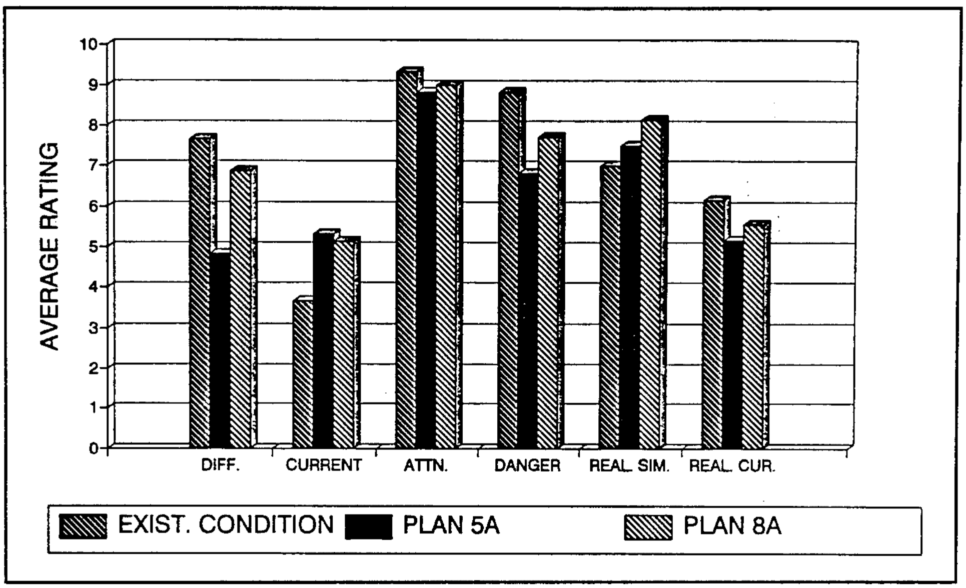



Figure 3. Ship pilot ratings, 228,000-cfs flow, downstream runs

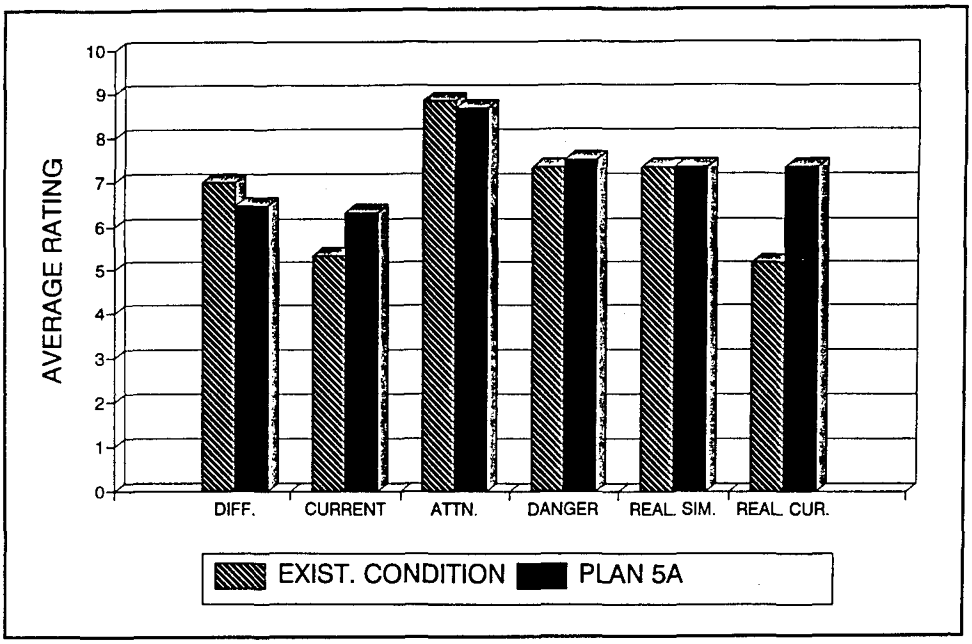



Figure 4. Ship pilot ratings, 450,000-cfs flow, upstream runs

**Downstream runs, 450,000-cfs flow.** Plan 5A rated nearly the same or higher in all questions than the existing condition (Figure 5). The pilots rated difficulty of run and current effects to be much higher than with the existing condition but rated the danger of striking an object or grounding only slightly higher.

**Upstream runs, 530,000-cfs flow.** The ratings for all questions, except current realism, are higher for Plan 8A than for the existing condition (Figure 6). The differences in the ratings are small except for attention required, which had a significantly higher rating.

**Downstream runs, 530,000-cfs flow.** The ratings for Plan 8A are equal to or higher than the existing condition for all questions (Figure 7). The differences in the ratings are small, except for danger of grounding or striking an object, which is significantly higher. Simulator realism is also rated much higher for the plan condition than with the existing condition.

**Upstream runs, 1,500,000-cfs flow.** Plan 8A was rated equal to or greater than both the existing condition and Plan 5A for all questions (Figure 8). Plan 5A was rated higher that the existing condition for difficulty, current effects, and danger of striking an object, but lower for attention required and realism of simulator and currents. The rating for attention required is much lower for Plan 5A than for the existing condition. This is not easily explainable, since the pilots rated difficulty and danger much higher for Plan 5A than for the existing condition.

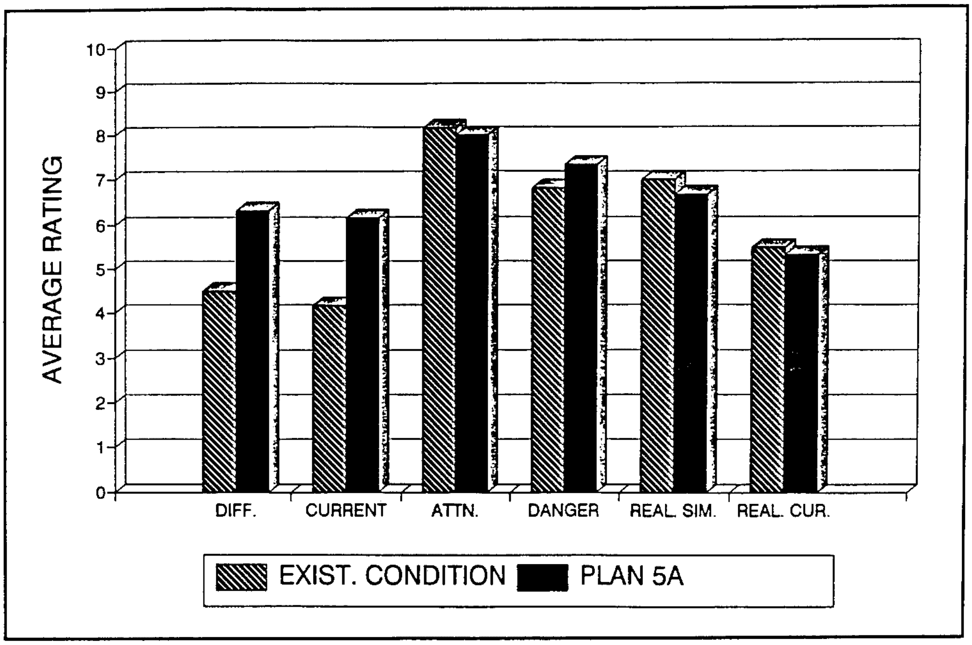



Figure 5. Ship pilot ratings, 450,000-cfs flow, downstream runs

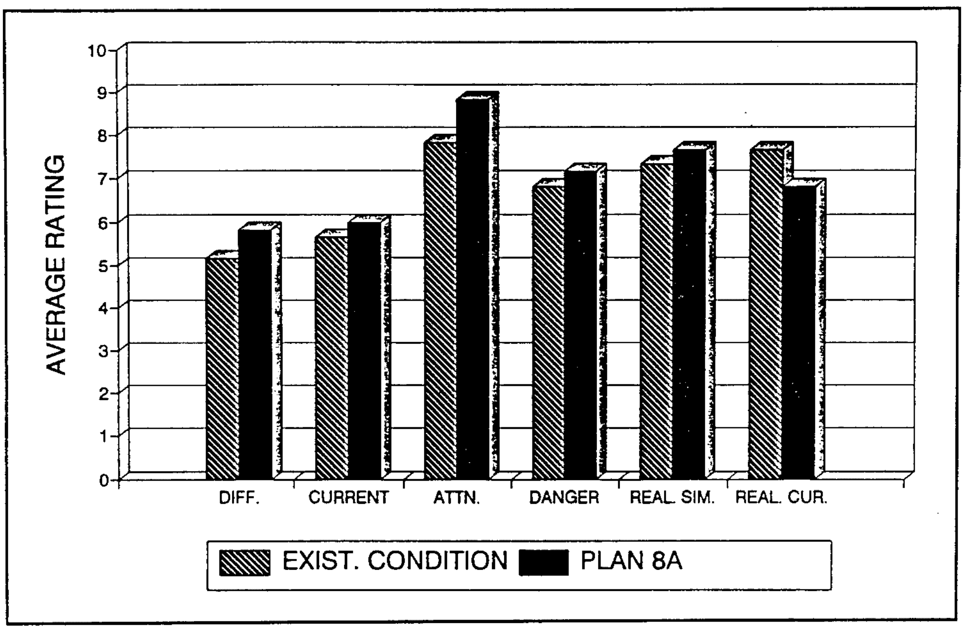



Figure 6. Ship pilot ratings, 530,000-cfs flow, upstream runs

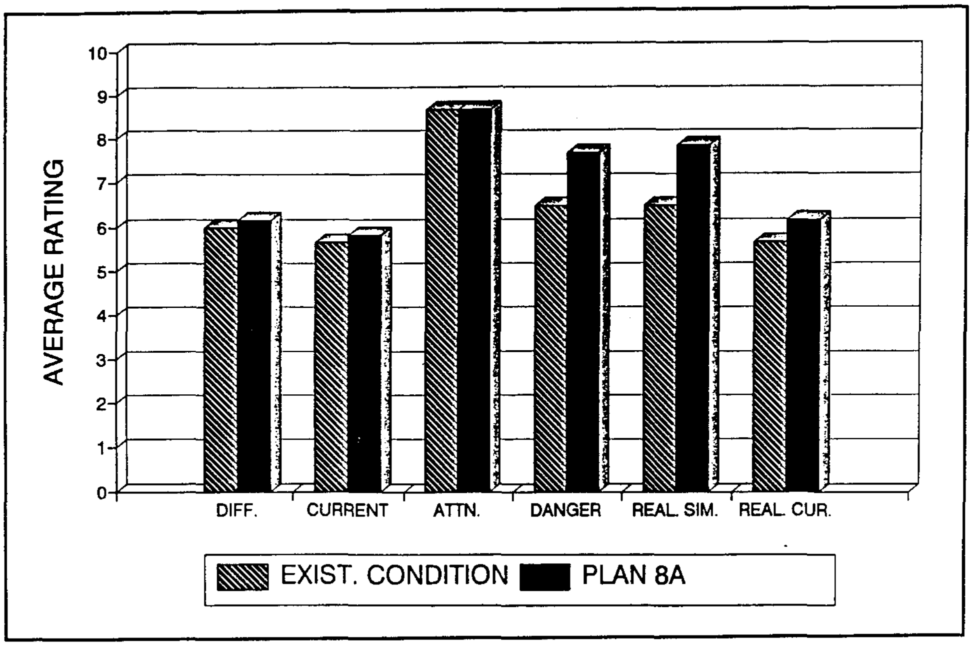



Figure 7. Ship pilot ratings, 530,000-cfs flow, downstream runs

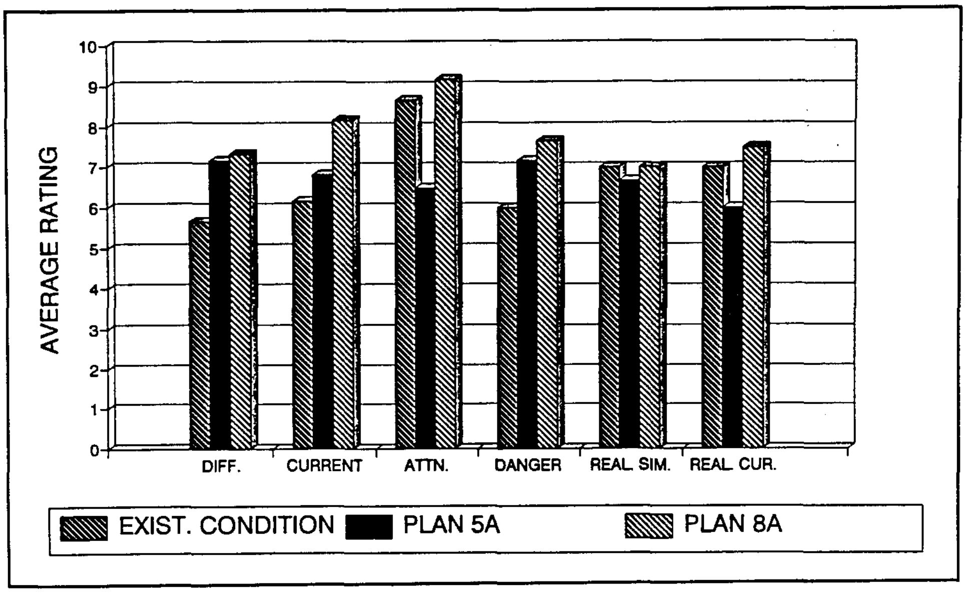



Figure 8. Ship pilot ratings, 1,500,000-cfs flow, upstream runs

**Downstream runs, 1,500,000-cfs flow**. Plan 5A is rated lower for all questions, except for danger of striking an object, than the existing condition (Figure 9). Plan 8A is rated nearly the same as or higher than the existing condition for all questions except for attention required, where it was rated slightly lower.

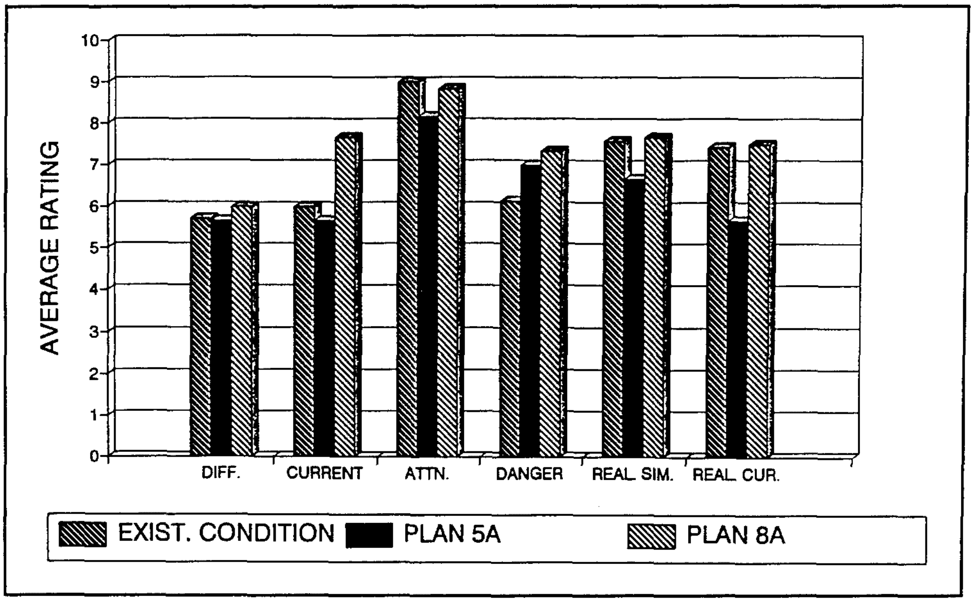



Figure 9. Ship pilot ratings, 1,500,000-cfs flow, downstream runs

**Summary**. For most conditions, Plan 5A was rated to be nearly the same as the existing condition. For the items of major concern (difficulty of run, attention required, and danger of grounding or hitting an object), most responses rated Plan 5A lower than the existing condition except for downstream runs at 450,000 cfs and upstream runs at 1,500,000 cfs. Plan 8A rated consistently higher for most questions for all conditions than either the existing condition or Plan 5A. Even though it rated higher for most conditions, the difference in the ratings from plan to plan was relatively small. Since Plans 5A and 8A were tested randomly with the existing condition, the prevalent thought of most of the pilots before the beginning of testing that the dikes would be a navigation hazard did not bias the results since Plan 5A was rated almost the same as or lower than the existing condition for most of the scenarios tested.

### Composite ship track plots

A complete set of the composite ship track plots for the channel test conditions is presented in Plates 11-30. The track plots also show the closest point that each pilot came to the ghost tow during his run. The minimum clearance distance between the ship and the tow is provided in Table 1. An area map,

providing the significant local landmarks used to describe the vessel location for the track plots, is provided in Figure 10.

**Upstream runs, 228,000-cfs flow**. The existing channel tracks (Plate 11) show all the pilots used almost the same strategy. They tended to start near the right descending channel edge below Dow Dock, then come to midchannel just downstream of Dow, staying near midchannel through the bend up past the lower ship ranges and through the crossing, then ease toward the left descending channel edge near the upper ship ranges. One pilot went slightly outside the right descending channel edge just upstream of the lower ship ranges but came back within the channel within a couple of ship lengths. All the pilots met and passed the ghost tow at the lower ship ranges. For Plan 5A (Plate 12), the pilots tended to run almost the exact same line as with the existing condition, except for being farther away from the right bank as they passed the lower ship range as the channel was wider at that point. They met and passed the ghost tow off the end of dike 6 (the most downstream dike). This is about the same location as passage in the existing channel. The tow was closer to the ship, probably due to the track that the ghost tow was forced to run, along the channel ends of the dikes, further away from the left bank than they would run without the dikes. Plan 8A (Plate 13) is again very similar to the existing channel and Plan 5A. For Plan 8A, the pilots tended to stay slightly farther away from the right bank at the lower ship ranges than with Plan 5A. They also met and passed the traffic tow off the end of dike 6. Although one ship track indicated a strong bank shear off the right decending bank below the lower range with resulting instability at the ranges due to being too close to the bank, none of the other tracks for the plan conditions indicated any particular difficulty; and all meeting and passing was performed with adequate clearances.

**Downstream runs, 228,000-cfs flow**. The downbound existing condition test runs (Plate 14) are an almost exact duplicate of the upstream runs. The pilots tended to be left of center channel as they passed the upper ship ranges, come to midchannel as they started through the crossing, and remain near midchannel through the bend till they passed Dow Dock, then moved toward the right bank. One pilot went slightly outside the right channel edge below Dow Dock but quickly came back into the channel. All the pilots met the traffic tow about midway between the lower ship ranges and Dow Dock. Plan 5A results (Plate 15) are very similar to the existing channel, except that the pilots took advantage of the wider channel and stayed farther away from the right bank as they passed the lower ship ranges than with the existing channel. They met the traffic tow at about the same point as with the existing channel. Plan 8A (Plate 16) is almost identical to Plan 5A. The pilots met and passed the traffic tow at the same place. Again, there were no apparent difficulties with the runs, and clearances with the traffic tow were more than adequate.

**Upstream runs, 450,000-cfs flow**. The existing condition test runs (Plate 17) show a similar pattern to the 228,000-cfs-flow runs. The pilots started out near or on top of the right descending channel edge downstream of

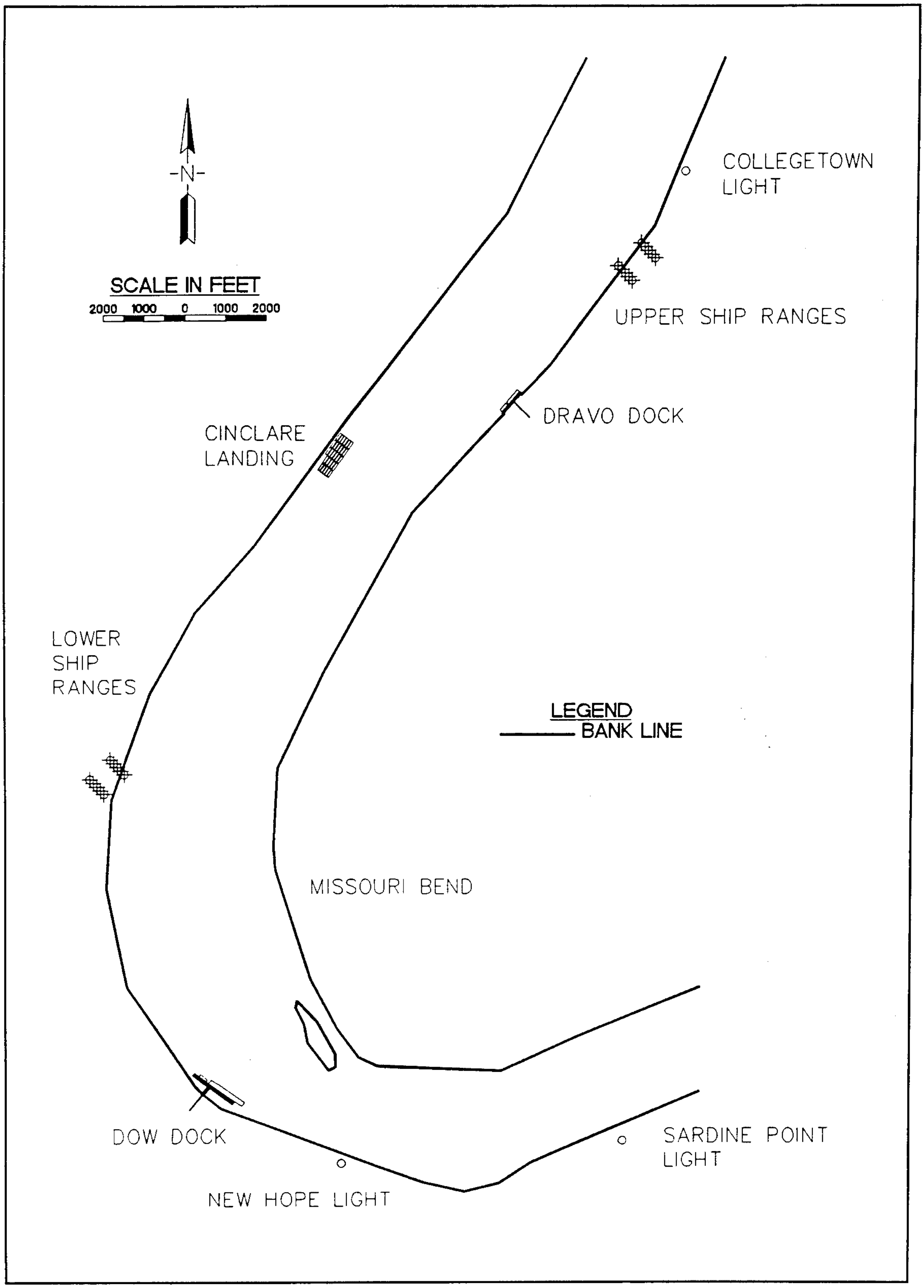



Figure 10. Area map showing landmarks for vessel locations in track plots

Dow Dock, moved to midchannel as they passed Dow and went through the bend, came near the right bank just upstream of the lower ship ranges, made the crossing, and moved to near the left bank. All pilots met and passed the traffic tow near the lower ship range. For Plan 5A (Plate 18), the pilots followed the same strategy up to the lower ship range. After they passed the lower ship range, they all tended to cross over to pass near the ends of dikes 1 through 4, then continue on upstream favoring the left side of the channel. The pilots met and passed the traffic tow off the end of dike 6, which is about the same location where they passed during the existing condition. There are no indications of any difficulties with any of these runs.

**Downstream runs, 450,000-cfs flow.** The existing condition runs (Plate 19) show that the pilots used a slightly different strategy than with the 228,000-cfs runs. The pilots started anywhere from midchannel to near the left bank just below the upper ship ranges, entered the crossing and neared the right bank upstream of the lower ship ranges, then came through the bend mostly favoring the right half of the navigation channel. One pilot went slightly out of the right channel edge upstream of the lower ship ranges, another just upstream of Dow Dock, and several below Dow. The pilots met and passed the traffic tow approximately midway between the lower ship ranges and Dow Dock. For Plan 5A (Plate 20), the pilots tended to stay near midchannel as they passed the upper ship ranges, then come to near the left channel edge, passing near the channel ends of the dikes. As they came out of the crossing and started into the bend, they crossed to the right side, and then favored the right side through completion of their runs. The pilots met and passed the traffic tow at approximately the same place as during the existing condition runs. The pilots tended to run near or outside the right channel edge below Dow Dock. No apparent difficulties were noted for this run condition.

Through all the runs examined so far, the pilots had a consistent tendency to go near or outside the defined right channel edge below Dow Dock. It would appear that it is common practice in real life to run near the right bank in this area and not considered to be risky or dangerous. It is possible that the defined channel edge in this area of the simulation is not where the pilots believe it to be, the bank effects that would tend to push the bow away from the bank are not as strong as they expect it to be, or a combination of both. Since this tendency occurred in both the existing and plan conditions, it cannot be attributed to the addition of dikes for either of the proposed plans.

**Upstream runs, 530,000-cfs flow.** The existing condition tracks (Plate 21) show that the pilots used basically the same strategy as with the 228,000-cfs flow. They started out near or slightly outside the right side of the defined channel below Dow Dock, came to midchannel and stayed there through the bend, went through the crossing near midchannel, then continued upstream favoring the left descending bank side of the channel. One pilot went well outside the right channel edge upstream of the lower ship range, possibly backing off the turn out of the bend a little early, but returned to the channel quickly. The pilots all tended to meet and pass the traffic tow off the

lower ship range. The Plan 8A tracks (Plate 22) show a very similar pattern to the existing condition tracks. The pilots followed basically the same line and appeared to have little to no difficulty making the run. They all met and passed the traffic tow off the end of dike 6, slightly upstream of the lower ship range.

**Downstream runs, 530,000-cfs flow**. For the existing condition, the pilots tended to follow the same track as with the upstream runs from the start of the runs to the lower ship ranges (Plate 23). As they passed the lower ship range, they tended to "crowd" the right descending bank and stay fairly close to the right bank for the remainder of the run. The pilots all met and passed the traffic tow approximately halfway between the lower ship ranges and Dow Dock. For Plan 8A (Plate 24), the pilots used almost the same track-line as the existing condition down to the lower ship range. From there, they tended to stay a little farther away from the right descending bank than during the existing condition runs but still favored the right side of the channel throughout the bend. The pilots all met and passed the traffic tow near Dow Dock. This is several thousand feet further downstream than during the existing condition, indicating that the ship was travelling much faster with the plan condition than with the existing condition.

**Upstream runs, 1,500,000-cfs flow**. Most pilots ran a track similar to that of the 530,000-cfs flows for the existing condition even though they had a much wider navigation channel (Plate 25). They all tended to stay further away from the right descending bank in Missouri Bend than in previous test conditions. One pilot went well toward the left bank in the crossing upstream of the lower ship ranges. His intent is not clearly understood. All pilots met and passed the traffic tow near the lower ship ranges. The tracks for Plan 5A (Plate 26) show a similar, but more erratic pattern than those for the existing condition. The pilots still tended to stay further away from the right descending bank in the bend, except for one pilot who came very near the bank just upstream of Dow Dock. As they came out of the bend and started into the crossing, most pilots steered a course to bring them off the ends of the dikes and continue upstream along the left descending bank. One pilot chose to stay near the right descending bank through the crossing, only crossing to the left bank after getting upstream of Cinclare Landing. All pilots met and passed the traffic tow near the end of dike 6. For Plan 8A (Plate 27), the track used by most of the pilots was similar to that of Plan 5A, but the pilots were more consistent in their track. They again stayed farther off the right bank in the bend and passed upstream off the ends of the dikes. All pilots met and passed the traffic tow off the end of dike 6.

**Downstream runs, 1,500,000-cfs flow**. The tracks for the existing condition (Plate 28) show that the pilots generally used the same strategy for navigating the reach. They started near the left descending bank at the upper ship ranges, held the left bank down to the crossing, moved to midchannel through the crossing, then held mostly along the right bank through the bend. Most pilots chose to go very near the right bank as they started their turn at the lower ship ranges, forcing them to stay near the bank through most of the

bend. It is clearly evident that one pilot chose to start his turn a little earlier, allowing him to stay well off the right bank, but bringing him much closer to the passing traffic tow. All pilots met and passed the traffic tow approximately midway between the lower ship ranges and Dow Dock. The tracks for Plan 5A (Plate 29) show that the pilots used basically the same strategy to complete their transits as with the existing condition. All the pilots tended to stay near the right bank through the bend. It appears that one pilot came near grounding along the right bank just downstream of the lower ship ranges. For Plan 8A (Plate 30), the pilots used the same basic strategy as with the existing condition and Plan 5A. They did manage to maintain a little more clearance from the right bank through the bend than they did with the other two conditions. Five of the pilots met and passed the traffic tow at about one-third of the distance between the lower ship ranges and Dow Dock. One pilot met and passed off the upstream end of Dow Dock, indicating that he made his transit much faster than any of the other pilots. None of the tracks indicate any particular difficulty with this condition.

### Statistical analysis

During each run, the control, positioning, and orientation parameters of the ship were recorded every 5 seconds. These parameters included position, speed, rpm of the propeller, and rudder angle. The statistical parameters were plotted against the distance along track. The distance along track is calculated by projecting the position of the ship center of gravity perpendicular to the center line of the channel and is measured from the beginning of the center line (Figure 11). Upstream runs are plotted from right to left and downstream runs are plotted from left to right.

For all parameters, the statistical analysis is presented as a mean of means within a sample channel section. A 500-ft channel section was used. This means that for each individual run, each parameter was averaged over 500 ft, and these means were averaged over all runs under a given condition, thus a mean of the means.

### Rudder angle

Rudder usage for the base and plan conditions is plotted in percent of maximum. Discussion of these plots will be by flow condition.

**228,000-cfs flow.** The plots for the upstream and downstream runs (Plates 31 and 32, respectively) show that rudder usage was almost the same for most of the runs for each plan condition, except in the Redeye Crossing and at the lower ship ranges. For the upstream runs, much more starboard rudder was used to turn out of Missouri Bend and into the crossing around dike 6 for both the plan channels than with the existing channel and much less port rudder was used to stop the turn within the crossing. For the downstream runs, the existing condition required extensive use of starboard rudder through the crossing, apparently to overcome a set to the port side. The plan

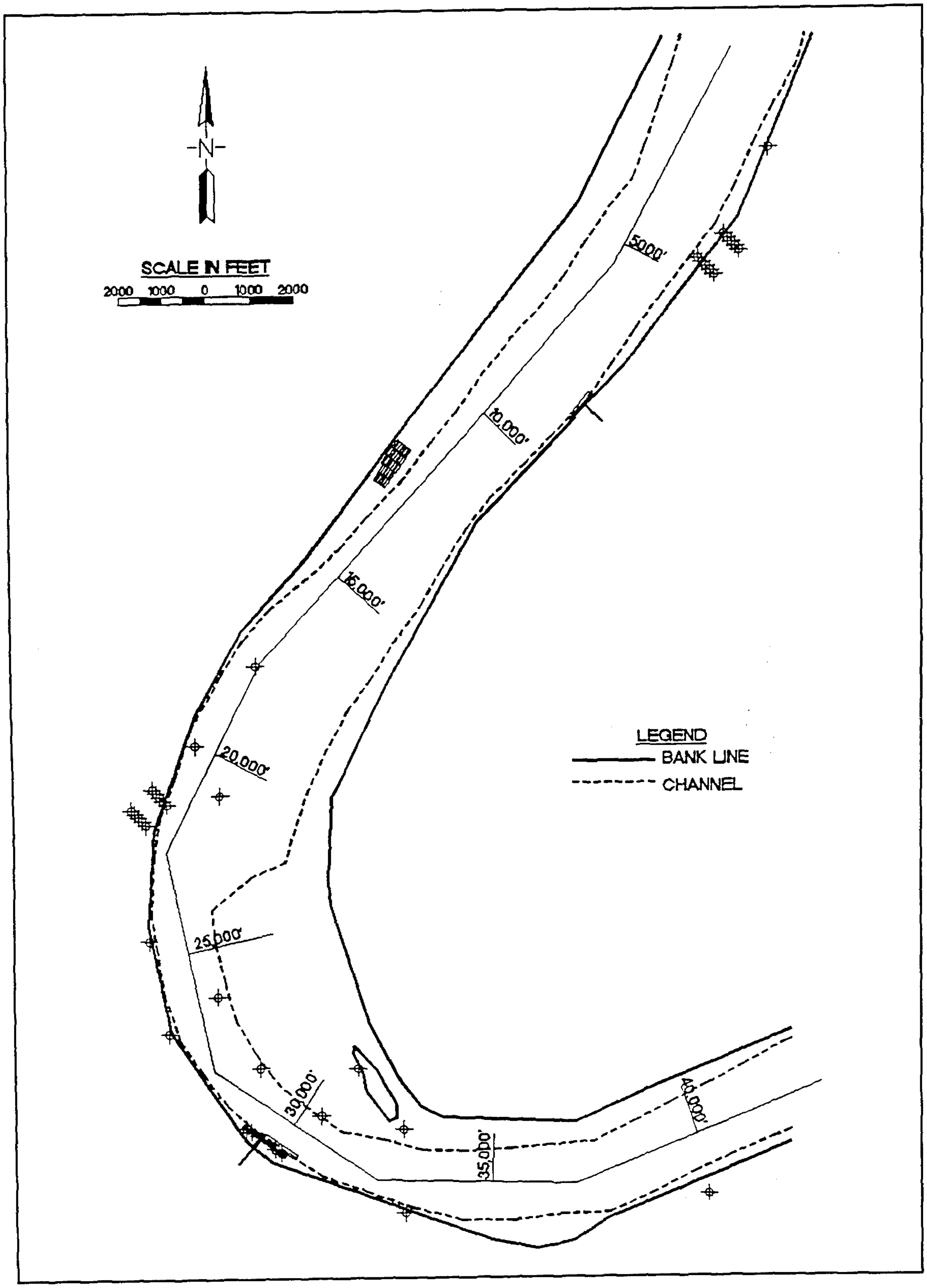



Figure 11. Distance along track

conditions show minimal use of rudder, either starboard or port, through the crossing.

**450,000-cfs flow.** The plots for the upstream run (Plate 33) show little difference between the existing channel and Plan 5A, except for a much larger use of starboard rudder for the plan condition as the pilots approached Dow Dock. The downstream run (Plate 34) shows little difference except at the upstream end of the crossing. For the existing condition, the pilots used a very large port rudder as they started into the crossing, then held starboard rudder through the crossing to overcome a port side set. For the plan channel, the pilots averaged holding a small port rudder setting throughout most of the crossing, using starboard rudder as they neared the end of the crossing and dike 6, then turned back to port to go through Missouri Bend.

**530,000-cfs flow.** The plots for the upstream run (Plate 35) again show little difference between the existing condition and Plan 8A rudder usage. The downstream runs (Plate 36) show similar usage down to about midway through the crossing. In the existing channel, the pilots averaged using a large amount of starboard rudder from midway through the crossing to near the end of the crossing before turning back to port to go through Missouri Bend. The plan condition averaged using port rudder throughout most of the crossing, then required a smaller amount of starboard rudder at the end of the crossing before going into Missouri Bend.

**1,500,000-cfs flow.** The plots for the upstream and downstream runs (Plates 37 and 38, respectively) show that the amounts of rudder and where it was applied were not very different for any of the conditions tested. Much smaller rudder usage was observed for this flow condiiton than for the other flows.

### Engine rpm and speed

Engine rpm is plotted in percent of maximum rpm, and speed is plotted in miles per hour. Discussion of these plots will be by flow condition. Upstream runs are plotted from right to left and downstream runs are plotted from left to right.

**228,000-cfs flow.** The upstream runs (Plate 39) show that the pilots used less average rpm in the Missouri Bend during the existing channel condition than with the two plan conditions. After about midway of the crossing, the engine usage was approximately the same for all conditions. The speed mirrors the rpm settings. The speed averaged during the existing condition runs was slightly less than with the plan conditions throughout the Missouri Bend and through the crossing but increased to be approximately equal with the plan conditions for the remainder of the runs. The downstream runs (Plate 40) again show that the pilots averaged using less rpm for the existing condition than for the plan conditions until they got through the crossing. After starting into the bend, the engine was run at almost maximum rpm

throughout the remainder of the run. The speed again reflects the usage of rpm. The speed with the existing channel was considerably slower from the start of the runs through the crossing, then picked up to approximately the same as with the plan conditions.

**450,000-cfs flow.** The plots for the upstream runs (Plate 41) show almost no differences in rpm or speed for the existing condition versus Plan 5A. The plots for the downstream runs (Plate 42) again show little difference. The existing condition runs averaged more rpm early in the run, up to the beginning of the crossing. The speed shows that the existing condition channel averaged slightly faster than Plan 5A up to the crossing, then the plan channel averaged being slightly faster than the existing through the crossing, even though rpm was about the same for both conditions. This would be due to the slight increase of current speed past the ends of the dikes for the plan condition.

**530,000-cfs flow.** The upstream runs (Plate 43) show that the existing condition used slightly less rpm for the entire run than Plan 8A. Speed for the existing condition was slightly slower than with Plan 8A through most of the run until the pilots got into the crossing, where they were apparently able to find slow current for the existing condition and their speed increased to be faster than that for the plan condition, even though they turned slightly fewer rpm. The downstream runs (Plate 44) show that rpm was almost the same for both the existing and plan conditions for most of the run until the pilots reached the Missouri Bend, and the existing condition used slightly less rpm for the remainder of the run. Speed for the two channel conditions was identical until the end of the crossing, then the Plan 8A runs averaged slightly faster throughout the remainder of the run. This could be due to both the slight reduction of rpm for the existing condition runs and the slightly increased current speed with the dikes in place for Plan 8A.

**1,500,000-cfs flow.** The upstream runs (Plate 45) show that the existing condition and Plan 8A runs averaged almost maximum rpm for the entire run. Plan 5A averaged slightly less rpm, especially through the crossing. This is reflected in the speeds for the runs. Plan 8A was slower than the existing condition, especially through the crossing, due to the increased current speed off the ends of the dikes. Plan 5A was slower than Plan 8A due to the lowered engine rpm. The downstream runs (Plate 46) show that the existing channel runs averaged less rpm from the beginning of the run through the bend than the two plan conditions. The pilots also tended to use slightly more rpm for Plan 8A than they did for Plan 5A for a majority of the run. Speed for the existing condition was expectedly slower for almost the entire run than for the plan conditions. Plan 5A was about the same as or slightly faster than Plan 8A.

## Conclusions

Most of the pilots commented in their final questionnaires that they did not like the dikes for either Plan 5A or 8A and considered them to be a navigation hazard. The averaged ratings for individual runs indicated that the pilots found Plan 5A to be about the same as or slightly more difficult than the existing condition and Plan 8A to be slightly more difficult than both the existing condition and Plan 5A. The track plots did not indicate any significant increase in difficulty for either of the two plan conditions in comparison with the existing condition. All runs were completed without coming dangerously close to the dikes or the traffic tow, and most tracks showed little or no more difficulty in remaining within the defined navigation channel for the plan conditions versus the existing condition. The parameter plots again show no significant increase in difficulty in operating with the plan conditions as opposed to the existing conditions.

From examination of the pilot ratings, track plots, pilot comments, and ship parameters, it appears that Plan 5A will not adversely affect safety or operation of ships within this reach. Plan 8A appears to be slightly more difficult than Plan 5A but not significantly enough to seriously affect safety or operation. Restrictions on passing of ships and traffic tows will probably be desired to assure safety, especially during higher discharge/stage conditions; however, the track plots and minimum clearances between the ship and tow do not indicate a safety concern. Passage times through the reach did not appear to be greatly affected by either of the plan conditions, but it should be assumed that upbound traffic will require slightly more time.

# 3 Navigation Study, Small Tows

The second phase of the Redeye Crossing study involved testing with small tows (one, two, or four barges). Professional tow pilots who routinely travel the lower Mississippi River assisted to allow incorporation of their experience and familiarity with current conditions and handling of small tows in the study reach. These tests were conducted due to serious concerns expressed by the towing industry about the impacts of the dikes on the small tows, especially their ability to maneuver through the higher currents off the ends of the dikes.

## Validation

Normally, one or two pilots would be asked to come in to operate the simulator to validate and verify the current conditions, bank effects, and tow handling characteristics before actual testing would occur. The tow models used for this portion of the study had been validated during previous simulation studies, and the currents and bank forces had been validated by the ship pilots who had tested prior to the arrival of the small-tow pilots. Since previous validations existed for both tow models, currents, and bank effects for this portion of the study, no validation was performed for the small tows.

## Test Conditions

The plans tested in the simulation were derived from the numerical and physical model studies. The plans tested were as follows:

*a.* Existing condition.

*b.* Plan 5A Optimized: six-dike plan to maintain a 40-ft navigation channel.

*c.* Plan 8A Optimized: six-dike plan to maintain a 45-ft navigation channel.

The current conditions used to test the three plan conditions were based on stage height at the Baton Rouge gauge. The river discharges and corresponding stages used for testing are as follows:

*a.* 228,000 cfs, 7-ft stage.

*b.* 450,000 cfs, 17-ft stage.

*c.* 670,000 cfs, 23-ft stage.

*d.* 1,500,000 cfs, 43-ft stage.

Two intermediate discharge flows were used, based on which plan was being tested. The critical intermediate flow was established to be the minimum stage at which tow traffic would still be forced to stay within the deep-water channel and not go over the proposed dikes. When the small-tow tests were performed, the minimum depth criterion for passage over the dikes was set at 18 ft. This was increased after the ship tests were conducted because serious consideration was being given to allow tows to pass over the dikes after being overtopped by 18 ft. For Plan 5A Optimized, the maximum dike elevation was now designed to be +5 ft; therefore, a 17-ft stage (450,000 cfs) was tested as the minimum before tow traffic could safely pass over the dikes. Likewise, Plan 8A Optimized was tested at a stage of 23 ft, which was 16 ft over the design crest elevation of +7 ft. Current vectors for the existing condition are presented in Plates 47-50, Plan 5A in Plates 51-53, and Plan 8A in Plate 54. Plan 8A was tested only at the intermediate flow due to the limited time available for these tests and the long upbound transit times, which limited the number of tests that could be completed in the time available. The velocities encountered by the small tows were higher for Plan 5A at the low and high flows than for Plan 8A Optimized; therefore, Plan 5A was tested rather than Plan 8A Optimized.

For each run, a traffic ship was encountered. This ship was an autopiloted ghost vessel, running on a predetermined track based on the results of the ship tests conducted previously. The pilot of the tow was responsible for avoiding the ship, since the ghost ship was on autopilot and could not perform any avoidance maneuvers. The tow was always traveling in the opposite direction of the ghost ship.

The testing scenarios for small tows (two-barge) in the Redeye Crossing, Mississippi River, as implemented on the WES ship simulator consisted of the conditions in the following tabulation.

A few runs were made using one-barge and four-barge tow configurations, but neither of these configurations was tested over the full range of flow and plan conditions. The two-barge tow configuration was determined to be the most critical condition since the two-barge configuration usually used the same horsepower towboat as the one-barge, and normally a four-barge tow used a higher horsepower towboat.

| Plan | River Discharge, cfs | Direction |
|---|---|---|
| Existing | 228,000 | Upstream |
| | | Downstream |
| | 450,000 | Upstream |
| | | Downstream |
| | 670,000 | Upstream |
| | | Downstream |
| | 1,500,000 | Upstream |
| | | Downstream |
| 5A Optimized | 228,000 | Upstream |
| | | Downstream |
| | 450,000 | Upstream |
| | | Downstream |
| | 1,500,000 | Upstream |
| | | Downstream |
| 8A Optimized | 670,000 | Upstream |
| | | Downstream |

Four pilots (two each week for two consecutive weeks) operated the simulator and evaluated the simulation. Tests were conducted in a random order to avoid prejudicing the results, with the pilots alternating operation of the simulator after each simulation run. After each run, the pilot was asked to fill out a questionnaire to rate the simulation. At the completion of all testing, a final debriefing questionnaire was filled out by each pilot to get his comments on the existing condition, the proposed plans, and the simulator.

During each run, the characteristic parameters of the tow were automatically recorded every 5 seconds. These parameters included the position of the tow's center of gravity, speed, rpm of each engine, heading rate of turn, and rudder angle. As the tow approached and passed the traffic ship, the time during the simulation run and the position of the center of gravity of each vessel were recorded. This information is used to determine the minimum distance between the vessels during the run.

The simulator tests were evaluated on pilot comments, pilot ratings, ship tracks, and statistical analysis of tow control parameters recorded during testing. The following section will present the results of this analysis.

## Study Results

### Final questionnaire

After finishing all test runs, the pilots completed a final questionnaire to give their opinions on the project as well as on the simulation. Some of the comments made by the pilots on the project follow:

**1. How will the proposed dikes affect safety at Redeye Crossing?**

"The dikes make the channel more narrow and will make the possibility of collision higher in lower river. --In high river the smaller vessels will have to run over the dikes to give the larger vessels more room."
"It will make the crossing safer for ship and barge traffic."
"On 800 and 1000 hp boats at lower river stages you will have the problem of stalling out when Northbound...."
"At river stages of 20 ft or more, if northbound tow traffic which would normally run up the left descending bank are not allowed to go over the dikes, then these tows are going to be moving slower than usual. This may cause tows to be in the crossing channel longer which is a closer passing situation and therefore will increase the risk of accidents with other vessels."

**2. How will ship and barge traffic be affected by the proposed dikes?**

"During high water periods when southbound tow traffic would normally run down the pointway at Conrad Point, the dikes will cause tow(s) to be farther out in the river than normal. This will be especially hazardous for long tows if they should be meeting a ship near the lower dike. The long tows will tend to set off the dike into the bend. This could make for a close passing situation. If the dikes were not there, or could be navigated over, this situation would be avoided."
"There will be time lost running northbound waiting on larger tows and ships that are southbound."
"Ships will have a deeper and wider channel to navigate in low water conditions. Barge traffic will have a wider channel in low water conditions. But in high water, boats and barges will have a narrower channel unless they can run over the dikes."
"There will be times that there will be one way passing. The current after the dikes will be stronger. It will make it harder to come north and more dangerous going south due to the set towards the Dow Dock."

**3. Do you have any suggestions for changing the dike location or alignment that would improve navigation?**

"Don't put the dikes there at all."
"None."
"You might shorten the lower two dikes."

**4. Do you have any suggestions for improving the simulation?**

"The speed on the 1000 hp tow was too fast on the simulator not allowing [us] to see all [of the] effects of the current on the tow. Re-figure speed to around 5 mph northbound and 12 mph southbound using 28 ft river stage."
"You can't really get a feel or sense of the motion without peripheral vision. I would like to see a larger screen and side view screens to increase the feeling of reality."
"The simulation is great....I would like to see it when the barge touched the bank it would stop instead of going on out onto the bank."

**5. On a scale of 0 to 10 (10 being excellent), what is your overall opinion of the simulator and of the Redeye Crossing simulation?**

"The simulator is next to the real thing. It has proven to be very effective in the current flow. Also it has showed me a great deal of information that will be helpful to our pilots on our vessel."
"9"
"7. However, I feel that the tow is not responding properly to surface current, but more to the deeper currents as a ship would. The lack of lateral set southbound may be due to this or it could be from the excess speed if driving out of set or outrunning set."
"9. Overall the simulation was good. Was hard to see some sets when southbound. For the speed we were running there should have been real hard sets or sliding down around Dow Chemical."

**6. Comments?**

"Thanks for giving me the chance to work on this project. I hope my information has helped."
"I feel that if the dikes are designed so that tows can go over them at river stages above 22 ft, the effect may be minimal on small tows. However, if these small tows must stay in the channel then there will be a serious reduction in speed. I recommend removing dike markers at river stages that provide 15 ft of water over the dike. Consideration might be given to marking dikes with two types of markers. One would mark the dike, the other would be removed to indicate ability to go over the dike. I feel that the towboat in this program is responding more like an 1800 hp boat than a 1000 hp boat. I also feel that the bank forces are too great for reality."
"The simulator is great. I can think of many areas that could use a study done by it and the staff which works the simulator. It amazed me to see that adding dikes at Redeye Crossing actually helped in many ways. The simulation of Redeye without dikes is right on target. So I feel confident that the simulation with dikes is accurate as well."
"Good job, WES."

### Pilot ratings

After each individual run, the pilot was asked to rate several questions pertaining to the run he had just completed on a scale of 0 to 10. The ratings

of all four pilots for each run condition were averaged and plotted in bar chart form to allow direct comparison of the pilots' perception of each plan condition in relation to the other plan conditions. The questions asked concerned the following characteristics:

*a.* Difficulty of run.

*b.* Current effect on ship.

*c.* Amount of attention required.

*d.* Danger of grounding or striking object.

*e.* Realism of simulator.

*f.* Realism of currents.

**Upstream runs, 228,000-cfs flow.** The pilots rated the attention required and danger of grounding much higher for the existing condition than Plan 5A, even though they rated difficulty and current effect to be slightly higher for Plan 5A (Figure 12). The pilots rated the simulator and current realism to be fairly high.

**Downstream runs, 228,000-cfs flow.** The pilots rated difficulty, current effect, and attention a little higher for Plan 5A than the existing condition, but rated the danger of grounding to be slightly lower (Figure 13). Simulator and current realism were rated higher for Plan 5A than for the existing, but both got relatively high ratings.

**Upstream runs, 450,000-cfs flow.** The pilots rated all questions higher for Plan 5A than the existing condition (Figure 14). Difficulty, attention required, and danger of grounding received significantly higher ratings. Simulator and current realism received high ratings for both conditions.

**Downstream runs, 450,000-cfs flow.** Plan 5A received higher ratings for all questions except for attention required than the existing condition (Figure 15). The rating differences for all but the current realism were small, indicating that the pilots rated the two conditions as almost the same.

**Upstream runs, 670,000-cfs flow.** The pilots rated each question much higher for Plan 8A than the existing condition (Figure 16). The large differentials in the ratings indicate that the pilots found Plan 8A with this flow condition to be much more difficult.

**Downstream runs, 670,000-cfs flow.** The pilots again rated each question higher for Plan 8A than the existing condition (Figure 17). Although they rated the difficulty of run, current effects, and attention required much higher, they rated the danger of grounding to be slightly higher, indicating that they found the downbound runs to be more difficult than the upbound runs.

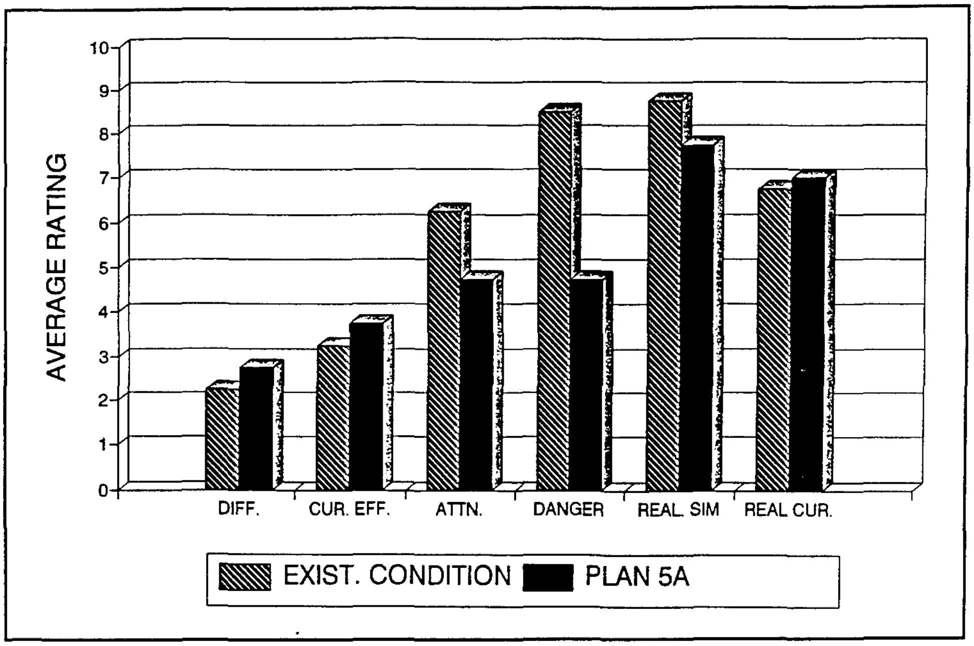



Figure 12. Small-tow pilots' ratings, 228,000-cfs flow, upstream runs

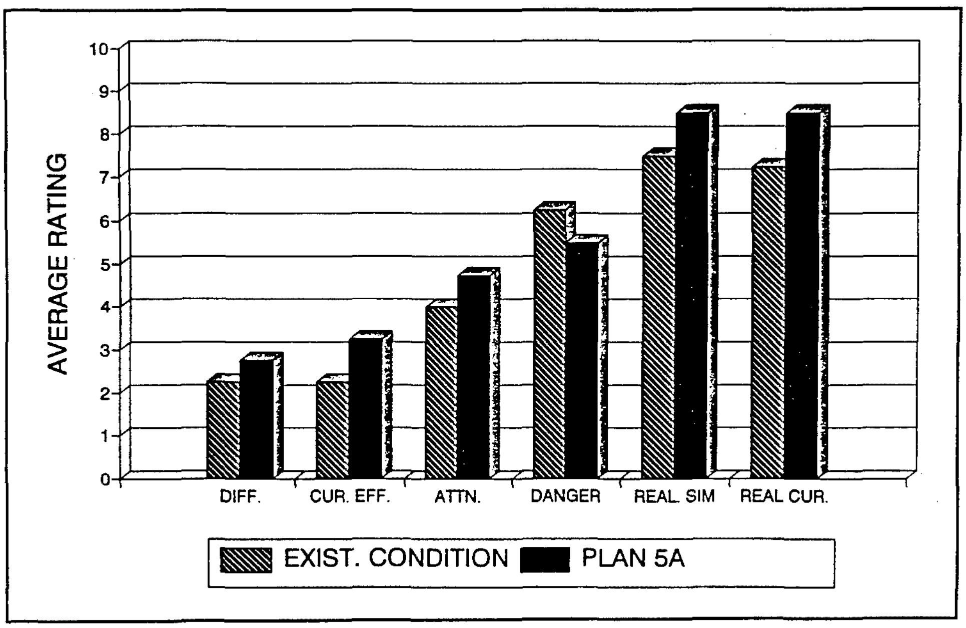



Figure 13. Small-tow pilots' ratings, 228,000-cfs flow, downstream runs

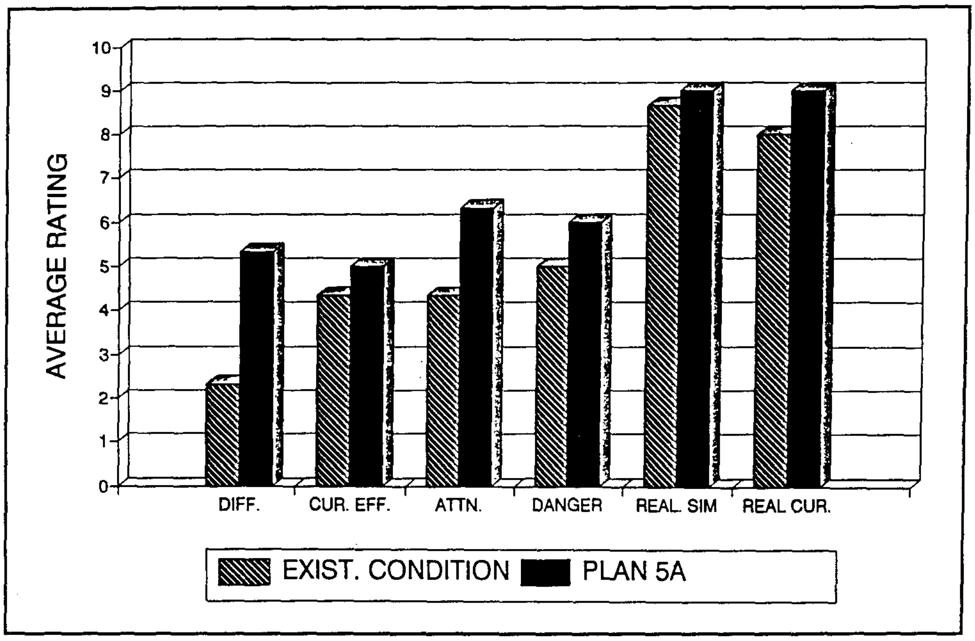



Figure 14. Small-tow pilots' ratings, 450,000-cfs flow, upstream runs

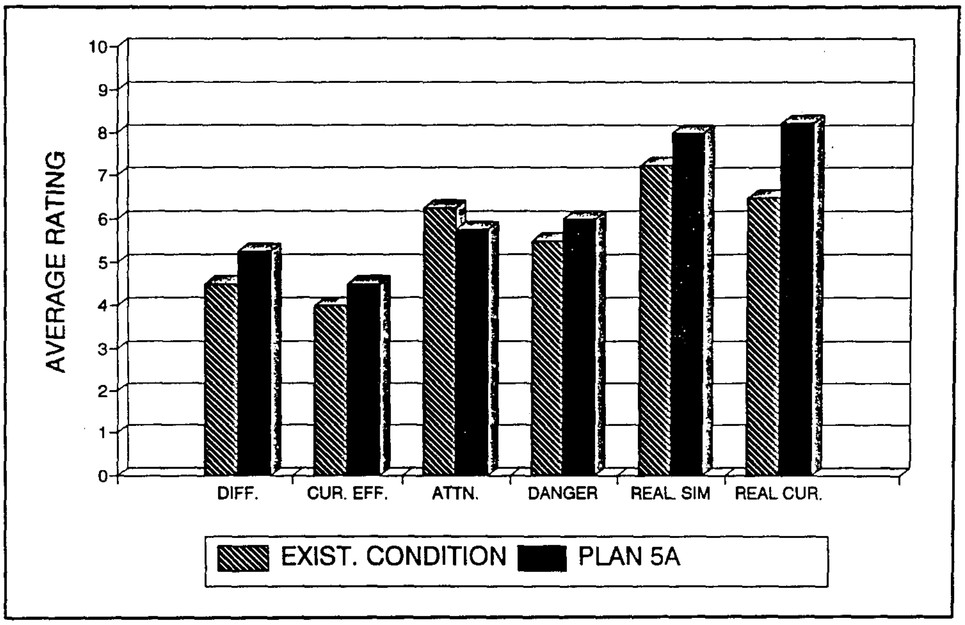



Figure 15. Small-tow pilots' ratings, 450,000-cfs flow, downstream runs

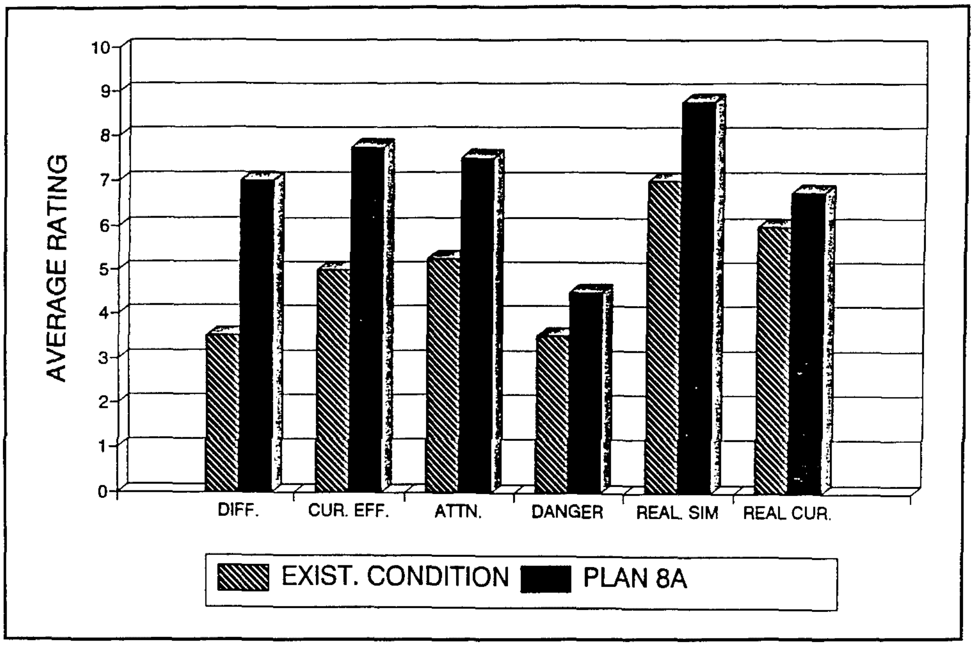



Figure 16. Small-tow pilots' ratings, 670,000-cfs flow, upstream runs

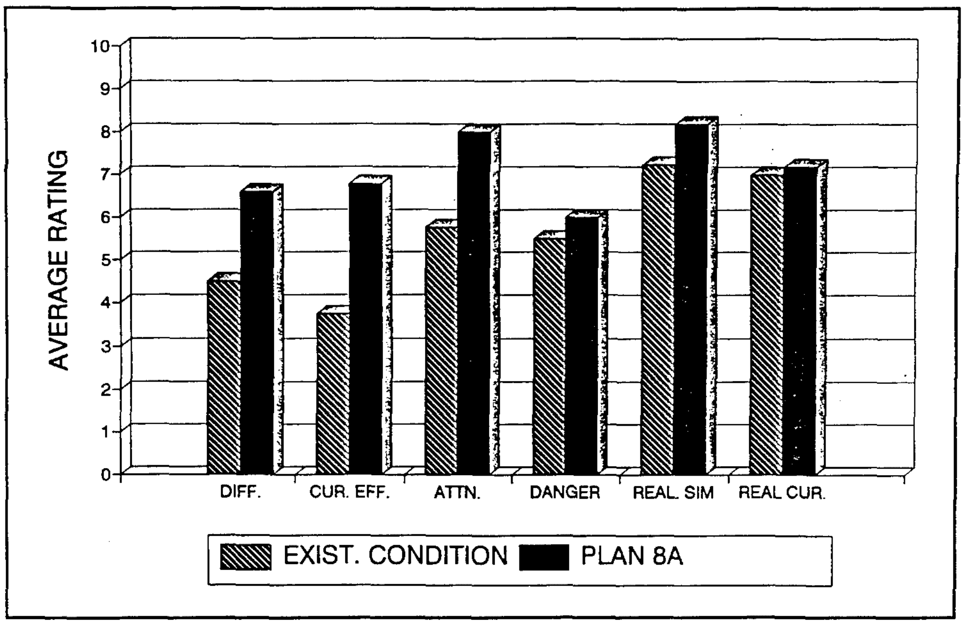



Figure 17. Small-tow pilots' ratings, 670,000-cfs flow, downstream runs

**Upstream runs, 1,500,000-cfs flow.** The pilots rated each question lower for Plan 5A than for the existing condition (Figure 18). The differences in the ratings for difficulty and current effects are negligible, but the ratings for attention required and danger of grounding are considerably lower for Plan 5A, suggesting that the runs with Plan 5A were somewhat easier to make than with the existing condition.

**Downstream runs, 1,500,000-cfs flow.** The pilots rated run difficulty, attention required, danger of grounding, and simulator realism higher for Plan 5A than for the existing condition (Figure 19). The differentials in the ratings for all questions were small, except for attention required and danger of grounding, in which the pilots clearly rated Plan 5A as much more difficult.

**Summary.** For most flow conditions and direction of travel, the pilots rated Plan 5A to be equal to or slightly more difficult than the existing condition. Plan 8A was clearly rated as much more difficult than the existing condition for the intermediate flow.

### Composite tow track plots

A complete set of the composite tow track plots for the channel test conditions is presented in Plates 55-70. The track plots also show the closest point that each individual pilot came to the ghost or traffic ship during their run. The minimum clearance distances between the tow and the ship are provided in Table 2.

**Upstream runs, 228,000-cfs flow.** For the existing condition, all the pilots started their runs and passed through Missouri Bend in almost identical fashion (Plate 55). After they met and passed the traffic ship just downstream of the lower ship ranges, they varied widely on where they chose to run. Two pilots moved almost immediately to the left descending bank and stayed near the bank through completion of their runs. The other two pilots moved toward the right descending bank after coming through Redeye Crossing and remained there through the completion of their runs. Apparently the pilots can run almost anywhere from bank to bank with this condition. For Plan 5A (Plate 56), the pilots tended to make more uniform transits. All the pilots ran up the defined left desending channel edge from the start of the runs, through Missouri Bend, past the ends of the dikes, on up past Dravo Dock and the upper ship ranges. There are several points at which at least one pilot went outside the defined channel edge, but these appear to be by choice rather than a control problem. For both existing and plan conditions, the tow passed the traffic ship with no difficulty.

**Downstream runs, 228,000-cfs flow.** For the existing condition (Plate 57), the pilots tended to have varying strategy in making the transit. As they passed downstream of the lower ship ranges they tended to run near

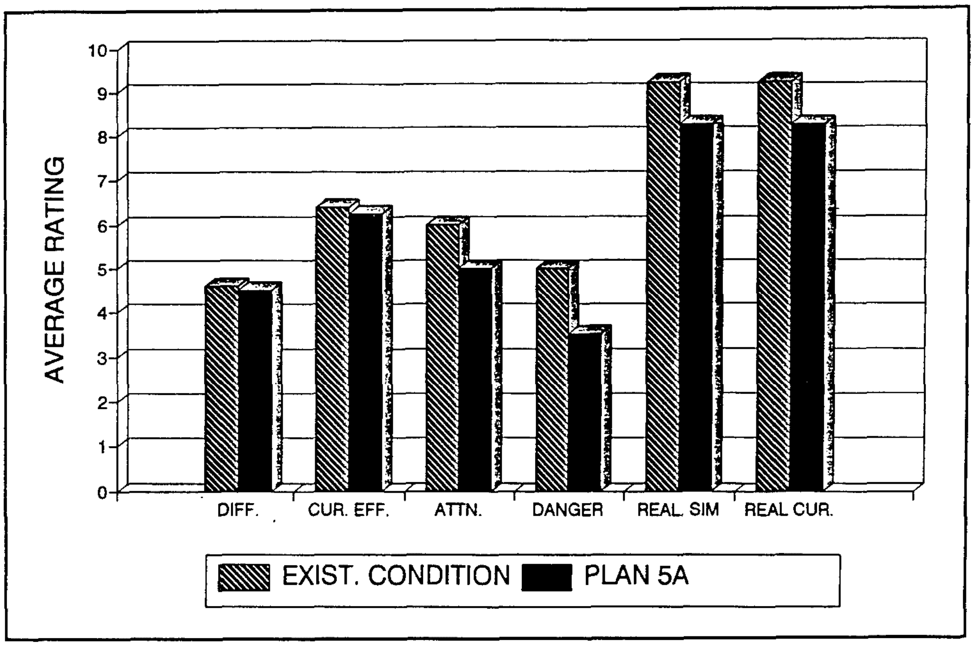



Figure 18. Small-tow pilots' ratings, 1,500,000-cfs flow, upstream runs

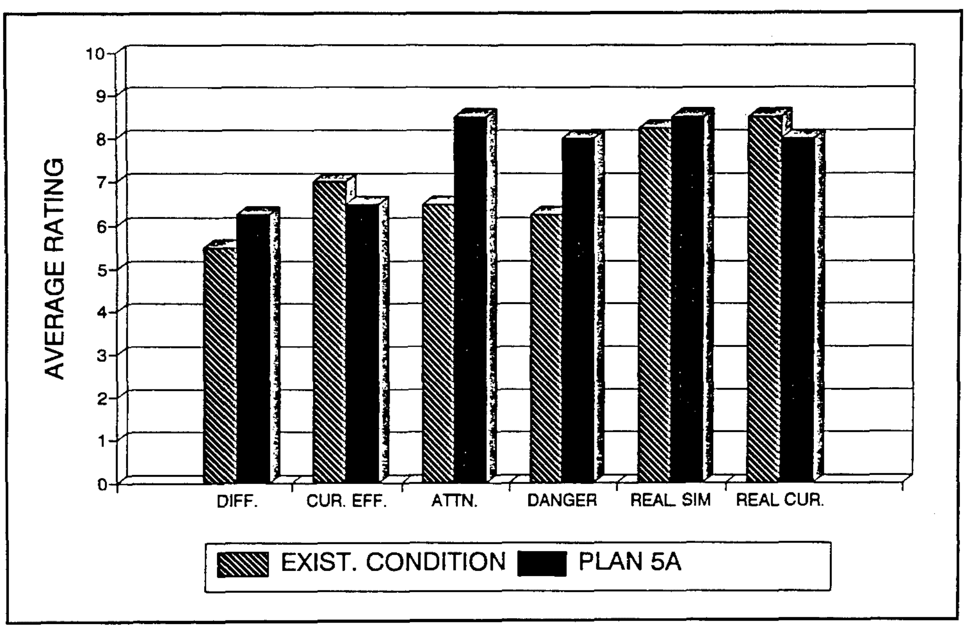



Figure 19. Small-tow pilots' ratings, 1,500,000-cfs flow, downstream runs

midchannel, then as they started into Missouri Bend, they all came near the left bank deep-water channel marker at the lower ship range. After they passed the traffic ship, two pilots continued to stay near the left descending channel edge, and the other two stayed out near midchannel and worked their way over to the right descending bank near the Sardine Point light. One pilot collided with the traffic ship at the left bank deep-water channel marker, opposite the lower ship range. The image of the passing ship was obscured for this run because it fell under the tracks of the tows. Clearance distances, listed in Table 2, show that the centers of gravity of the two vessels (tow and ship) passed 50 ft from each other. Since the ship is 138 ft wide, and the tow is 54 ft, this means that if the two vessels were abreast and touching each other, the distance between their centers of gravity would be 96 ft. For Plan 5A (Plate 58), the pilots ran more uniform runs through the crossing. The pilots started their runs along the right descending bank, came to midchannel well upstream of the crossing, then worked over to pass off the ends of the dikes until they passed the last dike, then again they split up, two running along the left channel edge and the other two favoring the right channel edge. The tracks do not indicate any difficulty with transits of the Plan 5A channel.

**Upstream runs, 450,000-cfs flow**. The existing condition tracks (Plate 59) show that the pilots all started out the same, but as they reached Dow Dock, they each had widely varying strategies. As they reached the foot of the island opposite Dow Dock, two pilots chose to stay within the deep-water channel, but one went outside the channel markers toward the left bank, came through the bend along the inside (left side), crossed to the right bank near the lower ship ranges, then continued upstream along the right descending bank. The other two pilots got past the traffic ship along the same track, then one turned toward the left bank. The second pilot continued on upstream within the deep-water channel, then at the lower ship ranges turned toward the left bank. Both pilots went up along the left bank till they reached Cinclare Landing, then they crossed to the right bank and continued along the right bank through the remainder of their runs. Only three pilots performed runs with this flow condition and direction. For Plan 5A (Plate 60), all the pilots used a more uniform strategy. All the pilots (only three pilots performed testing with this condition) started out along the left bank, stayed in the deep-water channel through Missouri Bend, continued past the ends of the dikes, and went up past the upper ship ranges along the left bank. One pilot varied slightly from the others in that he went outside the deep-water channel (behind the buoy) briefly as he approached the traffic ship. No apparent difficulties were noted in maintaining control or meeting and passing the traffic ship for either the existing condition or Plan 5A.

**Downstream runs, 450,000-cfs flow.** The existing condition runs (Plate 61) show that the pilots started out along the right descending bank, then tended to move out toward midchannel to near the left bank, but they grouped back up as they got into the crossing. As they completed the crossing, three pilots stayed along the inside of the bend along the deep-water channel markers till they got near Dow Dock where one of them moved down

close to the right bank and Dow Dock. The remaining pilot ran near the right bank till he approached the Dow Dock, then he moved toward midchannel. This pilot collided with the traffic ship. It is not understood why the pilot chose to drive his tow into what should have clearly been the ship's traffic lane, especially since he was in the same position within the channel as the other pilots as he approached the lower ship ranges. The other pilots passed without incident. All the pilots tended to finish their runs near midchannel. For Plan 5A (Plate 62), the pilots started along the right bank, but all moved toward the left bank before they reached Redeye Crossing and all passed along the ends of the dikes. As the pilots passed the fifth dike, three chose to stay close to the end of dike 6, but the fourth one came well out into the channel. They all tended to group back up as they passed Dow Dock, then two pilots went toward the left bank and the other two remained along the right bank. As with the existing conditions, two of the pilots came downstream faster than the other two pilots, causing them to meet the traffic ship in Missouri Bend instead of the downstream end of the crossing. Other than the one pilot who collided with the traffic ship in the existing condition tests, there were no apparent difficulties with any of the runs.

**Upstream runs, 670,000-cfs flow.** For the existing condition (Plate 63), all the pilots ran approximately the same track till they passed the foot of the island (sometimes referred to as towhead or Towhead Island). Three of the pilots turned along the island and stayed near the left descending bank through Missouri Bend. The fourth pilot stayed well out in the channel till he got up to the lower ship ranges, then he crossed toward the left bank. This pilot's run was terminated early, due to a simulator malfunction. Of the three pilots who came through the bend along the left bank, two stayed along the left bank up to near Cinclare Landing, then one of them crossed to the right bank, then they both continued upstream. The third pilot crossed from left to right within Redeye Crossing and continued upstream along the right bank. For Plan 8A (Plate 64), the pilots again used basically the same track till they reached the foot of the island. Two of the pilots stayed along the left bank and continued up past the ends of the dikes. One pilot crossed to the right bank at the island and remained along the right bank for the remainder of his run. The last pilot started toward the right bank, then changed his mind or possibly ran into difficulties with power in the higher currents, and moved back toward the left bank. He remained along the left side till he passed the last dike downstream. At that point, he worked his way immediately toward the right bank and completed his run along the right bank. The two pilots who remained along the left bank through the dikes worked their way toward the right bank as they reached the upstream end of Redeye Crossing, and they completed their runs along the right bank. The pilots appeared to have somewhat more difficulty staying out of the strong currents, especially with the dikes in place. All meeting and passing of the traffic vessel was performed without incident with both the existing condition and Plan 8A runs.

**Downstream runs, 670,000-cfs flow**. For the existing condition (Plate 65), the pilots started along the right bank then moved toward midchannel as they passed Dravo Dock. Two pilots chose to go through the

crossing and stay out in the deep-water channel through the bend. The other two pilots tended to stay nearer the left bank and cut across the inside of the bend. One of the pilots who stayed out in the deep-water channel had a near-miss with the traffic ship. The other pilots stayed well clear of the traffic ship. For Plan 8A (Plate 66), the pilots ran a uniform track from the beginning of the run down to the end of the last dike. After they passed the last dike, two pilots stayed well up toward the left side of the channel, passing near the foot of the island and completing their runs. The other two pilots went well down into the deep-water channel. One of these pilots got down too far toward the right bank and was set down close to Dow Dock. Meeting and passing of the traffic ship was accomplished with no incident. Except for the one pilot who set down towards Dow, the transits were made with no apparent difficulty.

**Upstream runs, 1,500,000-cfs flow**. For the existing condition (Plate 67), the pilots all hugged the left bankline through the bend and crossing to stay out of the strong currents in the deep-water channel. As the pilots approached the Cinclare Landing, three of them crossed to the right bank and continued on upstream, and the remaining pilot stayed on the left bank through the completion of his run. Clearance distances for the meeting and passing were large since the vessels were on opposite banks when they passed. For Plan 5A (Plate 68), the pilots held to the left bank till they reached the head of the island. Three of the pilots went around the dikes, two of them crossing to the right bank off the end of dike 3, and the other crossing after getting opposite of Cinclare Landing. The fourth pilot stayed on the left bank, crossing over the top of the dikes, till he got opposite of Cinclare Landing where he also crossed to the right bank and completed his run. Again, meeting and passing was accomplished with no difficulty since the vessels were on opposite sides of the channel when they passed.

**Downstream runs, 1,500,000-cfs flow**. For the existing condition (Plate 69), the pilots started near the right bank. One pilot chose to stay near the right bank through the crossing and into Missouri Bend, then turned toward the foot of the island as he approached Dow Dock and completed his run near midchannel. The other three pilots came to midchannel as they passed Cinclare Landing. From there, one stayed in midchannel through the crossing and into the bend and, as did the first pilot, turned toward the foot of the island before reaching Dow Dock. The other two pilots moved toward the left bank and stayed near it, passing close to the island, then coming back into the main channel. Meeting and passing of the traffic ship was performed with no apparent difficulty. For Plan 5A (Plate 70), the pilots started from the right bank and moved out to midchannel before reaching the crossing. All but one of the pilots went through the crossing just off the ends of the dikes, came across the inside of the bend, and off the foot of the island. One pilot came along the dikes till he reached dike 5, then moved well out into the deep-water channel at the lower ship ranges, then turned to come across the foot of the island. No difficulties were noted in meeting and passing the traffic ship.

## Statistical Analysis

During each run, the control, positioning, and orientation parameters of the tow were recorded every 5 seconds. These parameters included position, speed, rpm of each propeller, and rudder angle. The statistical parameters are plotted against the distance along track. The distance along track is calculated by projecting the position of the tow's center of gravity perpendicular to the center line of the channel and is measured from the beginning of the center line (Figure 11). Upstream runs are plotted from right to left and downstream runs are plotted from left to right.

For all parameters, the statistical analysis is presented as a mean of means within a sample channel section. A 500-ft channel section was used. This means that for each individual run, each parameter was averaged over 500 ft, and these means were averaged over all runs under a given condition, thus a mean of the means.

### Rudder angle

Rudder usage for the existing and plan conditions is plotted in percent of maximum. Discussion of these plots will be by flow condition.

**228,000-cfs flow.** The use of steering rudder for the upstream runs was very similar for the Plan 5A condition and the existing condition (Plate 71). The pilots did not use the flanking rudder for any maneuvers, but they inadvertently left the flanking rudder set at something slightly off of straight ahead (zero) for the runs. For the downstream runs (Plate 72), the use of rudder for both conditions is similar, except for the large use of port rudder near the lower ship ranges for the existing condition. The pilots tended to turn sharply as they passed the channel marker opposite of lower ship ranges. For Plan 5A, the marker was set back to the channel end of dike 6, allowing them to make a more gradual turn than with the existing condition.

**450,000-cfs flow.** For the upstream runs (Plate 73), the use of steering rudder was similar for both conditions. For the downstream runs (Plate 74), the use of rudder was similar for both conditions, except as they passed Dow Dock. Plan 5A runs required much higher use of port rudder to complete the turn through Missouri Bend. The track plots of the runs (Plates 61 and 62) do not indicate control problems. It is apparent from the tracks that the pilots used a more gradual turn with the existing condition than with the plan condition. The pilots tended to cut across the bend with the plan condition, requiring a sharper turn near Dow Dock. The large use of rudder might also indicate a stronger tendency to "slide" (move laterally) with the plan condition than with the existing condition.

**670,000-cfs flow.** For the upstream runs (Plate 75), rudder usage was similar for both the existing condition and Plan 8A. For the downstream

condition (Plate 76), the rudder usage is similar down to the lower ship ranges. After this point, the pilots for the existing condition used gradual port rudder for most of the bend. For the Plan 8A condition, the pilots averaged turning to starboard after passing the lower ship ranges, then turned back hard to port before coming back to a more gradual use of rudder near the end of the runs. It can be observed from the track plots for the two conditions (Plates 65 and 66) that the pilots took wide sweeping turns through Missouri Bend for the existing condition, not requiring large application of port rudder. For the Plan 8A condition, one pilot took a gradual sweeping turn along the inside of the bend. Three pilots turned to starboard after passing dike 6 to bring them well down in the bend. As they approached Dow Dock, they required large usage of port rudder to turn them before they hit the dock. If all of the pilots had chosen to make their transits across the inside of the bend, as did one pilot, the rudder usage would probably have been very similar to the existing condition.

**1,500,000-cfs flow.** For the upstream runs (Plate 77), the rudder usage is very similar for both conditions. For the downstream runs (Plate 78), the rudder usage is similar, except for the large use of starboard rudder during the Plan 5A condition near Dow Dock. Examining the track plots for this condition (Plate 70) reveals that two of the pilots turned off the foot of the island to push their tows away from the left bank toward midchannel. This does not appear to be a control problem but rather a decision by the pilots.

### Engine rpm and speed

Engine rpm is plotted in percent of maximum rpm for each engine and speed is plotted in miles per hour. Discussion of these plots will be by flow condition. Upstream runs are plotted from right to left and downstream runs are plotted from left to right.

**228,000-cfs flow.** For the upstream runs (Plate 79), engine rpm was generally at maximum, except during the Plan 5A condition for a space of several thousand feet upstream and downstream of the lower ship ranges. This is the area where the tow met and passed the traffic ship. At least one pilot pulled back the engines during this area, thus reducing the average rpm for the plot. The speed for the Plan 5A condition is slightly slower than for the existing condition, especially near the lower ship range where engine rpm was reduced. For the downstream runs (Plate 80), the pilots all used maximum rpm during the existing condition but ran with reduced rpm for a majority of the runs for Plan 5A. Why the pilots averaged reduced power over such a long span is not clearly understood, since they reduced power well upstream of meeting the traffic ship and maintained the lower rpm settings to well below Dow Dock. One pilot mentioned in this questionnaire that the tow was too fast, so one or more pilots may have reduced power to slow their speed. Speed for the transit is about the same in the areas where full engine rpm was used for both conditions and up to 1.5 mph slower for Plan 5A than for the existing condition where the rpm was reduced.

**450,000-cfs flow.** For the upstream runs (Plate 81), the engines were run at maximum rpm for almost the entire transit for both conditions. Speed is about the same for both conditions, except in Missouri Bend between the lower ship ranges and Dow Dock where Plan 5A was up to 1 mph faster. When the track plots for these runs are examined (Plates 59 and 60), it can be noted that the tracks for Plan 5A tended to stay closer to the left bank through the bend, taking advantage of slower currents downstream of the dike field, thereby improving their speed. For the downstream runs (Plate 82), the pilots again ran the engines at maximum rpm for almost the entire transit. Speed is almost identical except for Plan 5A near Dow Dock being up to 1 mph slower than the existing condition. The loss of speed is likely due to the large application of rudder as described in the discussion of 450,000-cfs flow in the previous section during this portion of the Plan 5A runs.

**670,000-cfs flow.** For the upstream runs (Plate 83), Plan 8A runs start out at maximum rpm and existing condition runs start out with reduced rpm. This would indicate that one or more pilots did not use full power. Just before Dow Dock, rpm for the Plan 8A runs was reduced to about that of the existing condition runs. As the runs for both conditions reached Cinclare Landing, the pilots all increased power to maximum. Why the pilots ran with reduced power for such a long period is not clear. The speed for Plan 8A is less than that for the existing condition for most of the transit. The largest difference in speed was near the lower ship range, which would be off the end of dike 6 and in the strongest currents for Plan 8A. At that point, the speed for Plan 8A was approximately 4 mph slower than that of the existing condition. At the completion of the runs, the speed differential was about 1 mph. For the downstream runs (Plate 84), the pilots used maximum rpm for both conditions for almost the entire transits, except for two brief areas where one pilot apparently stopped the engines, thinking that he had completed his run. The speed for Plan 8A averaged higher than for the existing condition for the entire run. The highest speed differential was again near the lower ship ranges where Plan 8A averaged being about 3 mph faster than the existing condition.

**1,500,000-cfs flow.** For the upstream runs (Plate 85), the pilots all averaged maximum rpm for both channel conditions for almost the entire transit. Speed averaged a little higher for Plan 5A from the start of the run, through Missouri Bend, and up to the lower ship ranges. From there, the speeds for both channel conditions were almost identical. One explanation for the speed increase for Plan 5A is that the currents along the inside of the bend below the dike field were reduced compared with those of the existing condition, due to the dikes. For the downstream runs (Plate 86), the pilots ran the existing condition at maximum rpm for the entire run, but at least one pilot ran with reduced power for Plan 5A from the start of the run down to near Dow Dock. This is reflected in the speeds, which shows Plan 5A being slower than the existing condition by about 1 mph from the start of the run to Dow Dock. Once the engines were increased to maximum power for Plan 5A, the speed for Plan 5A came up to equal or slightly exceeding the existing condition near the end of the runs.

## Conclusions

The comments made by the pilots in their final questionnaires indicate that most of them do not favor dikes and considered them to be safety hazards. One pilot did favor the Plan 5A channel over the existing channel. Their average ratings for each plan and flow condition show that they rated Plan 5A to be the same as or slightly more difficult than the existing condition. However, they did rate the plan channel to be less difficult for some of the conditions tested. They rated Plan 8A to be much more difficult than either Plan 5A or the existing condition for the intermediate flow condition.

The track plots did not reveal any serious difficulties with any of the channels tested. For the most part, the transits were made, upstream or downstream, with little difficulty. The two occasions that the vessels collided were likely due to some indecision by the pilots on where the ship would be running in the channel. Since the ship was set on autopilot, it ran a fixed track at a fixed speed. In reality, the pilots of the tow and ship would be in contact by radio, and determination on where the ship would run within the channel would be firmly established. However, these tests demonstrate that in the case of miscommunication or slow decisions, control of the vessels can be difficult in these currents and close calls and collisions result.

The parameter plots did not indicate any particular increase of difficulty with either Plan 5A or 8A over the existing condition. The occasions where there was more rudder usage can be traced to deliberate decisions by the pilots on where they would run within the channel. Speed was not greatly affected on most of the Plan 5A runs. The upstream runs with Plan 8A had greatly reduced speed, especially through the dike field.

The following conclusions were reached for the small-tow testing program:

*a.* Plan 5A will increase operational difficulty slightly but not enough to seriously affect safety of operation.

*b.* Upstream operation with Plan 5A will be slightly slower than with the existing condition.

*c.* Downstream operation with Plan 5A will be the same or slightly faster than with the existing condition.

*d.* Meeting and passing of the small tow and traffic vessels can be accomplished with a minimal increase of difficulty with Plan 5A.

*e.* Plan 8A appears to significantly reduce upstream speed for the flow condition tested.

## Recommendations

The following recommendations are made for the small-tow testing program:

*a.* Traffic (shallow-draft tows) should be allowed to transit over the dikes when there is sufficient depth to allow safe passage.

*b.* Guidelines should be established on meeting and passing procedures for vessels within the Redeye Crossing during river stages that would require tows and ships to be within the deep-water channel if a dike plan is adopted.

*c.* Further testing should be performed with small tows if Plan 8A is adopted, due to the limited testing with this plan and the drastically reduced upbound speed with the one flow condition tested.

# 4 Navigation Study, Large Tows

The third phase of validation and testing was with large tows. Using professional pilots who routinely travel the lower Mississippi River on line-haul tows allowed incorporation of their experience and familiarity with current conditions and handling of large tows in the study reach. For all runs, the traffic ghost ship was set to run downstream. The tow pilots stated that during lower river stages the ships usually could overtake and pass the slower tows going downstream, and this was a more critical condition than a downbound tow meeting an upbound ship.

## Validation

The simulation for the large-tow scenarios was validated over a 5-day period with the assistance of two pilots licensed to operate large tows in the lower Mississippi River. The following information was verified and fine-tuned during validation:

*a.* Tow models.

(1) 25-barge tow, 5,600-hp boat.

(2) 49-barge tow, 10,500-hp boat.

*b.* The channel definition.

(1) Bank conditions.

(2) Currents.

*c.* The visual scene and radar image of the study area.

(1) Location of all aids to navigation.

(2) Location and orientation of the docks, fleeted vessels, etc.

(3) Location of buildings and visual cues visible from the vessel.

Testing of the 49-barge tow (20 loaded, 29 empty) required a 10,500-hp boat with three screws (propellers). This model did not exist and required a new tow model to be developed. This model was developed by BMT International, Inc., of Columbia, MD.[1] The newly developed model was tested by the two validation pilots and judged to be satisfactory without any modification. The model of the 25-barge (all loaded) tow with a 5,600-hp boat was available. The validation pilots noted sluggish response on this tow. This was improved by increasing the available power until both pilots agreed it was responding as would be expected.

The pilots were allowed to make simulation runs with randomly selected parameters of flow condition, existing or plan condition, and direction of travel, then asked to give their impression of current effects, bank effects, tow handling characteristics, radar image, visual scene, and anything else that might affect the simulation. The validation pilots noted strong currents in runs made with the 670,000- and 1,500,000-cfs flows but did not indicate that the currents were excessively strong. The pilots had no comments on the bank effects during validation.

The pilots noted discrepancies in the placement of buoys in the visual and radar scenes. One pilot noted that the normal range used for radar was 2.00 miles, not 1.80 miles, as the simulation radar indicated. The pilots also noted that the rate-of-turn meter on the tow console moved only slightly even when the rudder was hard over to port or starboard and the Doppler speed indicator showed the tow with a high rate of turn. The rate-of-turn indicator was adjusted to register more accurately, the radar range was modified, and the buoy positions corrected.

## Test Conditions

The Redeye Crossing, Mississippi River, testing scenarios as implemented on the WES ship simulator are listed in the following tabulation. Plan 5A was dropped from consideration by the time testing with the large tows took place. All downstream runs were made using the 25-loaded-barge tow with a 5,600-hp, twin-screw boat. All upstream runs were made using the 49-barge (20 loaded and 29 empty) tow with a 10,500-hp, triple-screw boat. This method of operation was based on discussions with towing company representatives and reflected normal operating practices. For each run, a traffic ship passed downstream through the test reach. Current vectors for the existing

[1] V. K. Ankudinov. (1991). "Hydrodynamic and mathematical model for ship maneuvering simulations of a 49 barge tow with triple propellers in support of WES for Lower Mississippi Crossing navigation study," Prepared for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, by BMT International, Inc., Columbia, MD.

| Stage at Baton Rouge, ft | Plan | Direction | Discharge cfs |
|---|---|---|---|
| 7 | Existing | Downstream | 228,000 |
| 23 | | | 670,000 |
| 43 | | | 1,500,000 |
| 7 | | Upstream | 228,000 |
| 23 | | | 670,000 |
| 43 | | | 1,500,000 |
| 7 | 8A | Downstream | 228,000 |
| 23 | | | 670,000 |
| 43 | | | 1,500,000 |
| 7 | | Upstream | 228,000 |
| 23 | | | 670,000 |
| 43 | | | 1,500,000 |

channel are presented in Plates 47, 49, and 50 and for the Plan 8A channel in Plates 54, 87, and 88.

Six pilots (two each week for three consecutive weeks) were used to operate and evaluate the simulation. Tests were conducted in a random order to avoid prejudicing the results, with the pilots alternating operation of the simulator after each simulation run. After each run, the pilot was asked to fill out a questionnaire to rate the simulation. At the completion of all testing, a final debriefing questionnaire was filled out by each pilot to get his comments on the existing condition, the proposed plan, and the simulator.

During each run, the characteristic parameters of the tow were automatically recorded every 5 seconds. These parameters included the position of the tow's center of gravity, speed, rpm of each engine, heading, rate of turn, and rudder angle. Data were also recorded when the traffic ship and the tow closed within approximately 2,000 ft of each other. This information includes the time during the simulation run and position of the center of gravity of each vessel. This information was used to determine the minimum distance between the vessels during each run.

The simulator tests were evaluated on pilot ratings, ship tracks, statistical analysis of tow control parameters recorded during testing, and pilot comments from the questionnaires and final debriefings. The following section will present the results of this analysis.

## Study Results

### Pilot comments

**Pilot run questionnaires.** This group of pilots made their comments during the individual runs. These comments are as follows:

*a.* *Downstream runs, 228,000-cfs flow.* (existing) "Some slide onto Dow Dock." "Strong draft just above Dow Dock (right-hand draft)." (plan) "Draft on Dow Dock." "I would assume a set toward the dikes."

*b.* *Downstream runs, 670,000-cfs flow.* (plan) "Fastest stage with dikes." "Red buoys across from the Dow Dock would not be in place @ 23' on the Baton Rouge Gage. We would normally hold the island closer after clearing the proposed dikes." "Current set too strong for 23' on Baton Rouge Gage."

*c.* *Downstream runs, 1,500,000-cfs flow.* (plan) "Very realistic on this run." "Southbound above the island at Conrad Point, the effects of the slide were corrected too quickly. The tonnage of the tow would have continued the slide much longer."

*d.* *Upstream runs, 228,000-cfs flow.* (existing) "Too much effect of setting away from right descending bank above Collegetown Light." "Does not handle properly in less than 20 ft." (plan) "The effect of current setting the tow away from the bank is too strong-particularly in a lower river stage." "Right-hand draft between #5 and #6 dike."

*e.* *Upstream runs, 670,000-cfs flow.* (existing) "Tow sets away from shore in a couple of places that it shouldn't...." "The 'bank-effect' setting the tow away from the shore is much stronger than 'real life.'" (plan) "Very swift at Dow Dock." "Strong currents caused by dikes make it necessary to cut corners to avoid ship and make time."

*f.* *Upstream runs, 1,500,000-cfs flow.* (existing) "No chance of grounding, but due to heavy flow, there is a danger of landing on island, dock, or shore." "While pointing into right descending bank there is a set off shore (while tow sets out) that should not be there." (plan) "This is the most realistic run I've made." "Very little reaction at dikes."

**Final debriefing.** The pilots generally agreed that the proposed plan would not affect safety to a great extent and would probably limit where ship and barge traffic would pass. All the pilots also saw a need for improvement (or refinement) of the behavior of the tow in shallow water and near the bank lines. The pilots' average rating of the simulator on a scale of 1 to 10 was 7.5, and most pilots expressed the opinion that the simulator (simulation) was adequate for the required testing.

## Pilot ratings

After each simulation run, the pilot completed a questionnaire rating the effects on the tow and the simulation. The ratings were tabulated and averaged, then plotted in bar chart form to compare the existing condition versus the plan condition for each flow and direction scenario.

**228,000-cfs flow.** Ratings for the downstream and upstream runs with a 228,000-cfs flow (Figures 20 and 21) indicate that the pilots saw almost no differences in operation with either the existing or plan condition. They rated the difficulty of the run lower with dikes than without, even though they rated the effects of the current on the tow to be slightly higher with dikes.

**670,000-cfs flow.** The largest differences in ratings from existing to plan was with the 670,000-cfs flow (Figures 22 and 23). For both the upstream and downstream runs, the pilots consistently rated the plan condition much higher for degree of difficulty, current effect on the tow, attention required, and danger of striking an object. Rating of the simulator handling and realism of current effect were higher for the plan than for the existing condition for the upstream runs. Clearly, the pilots viewed the 670,000-cfs-flow condition to be the most difficult to operate. This will be examined further in the track plots and statistical analysis.

**1,500,000-cfs flow.** The ratings for the runs with a 1,500,000-cfs flow (Figures 24 and 25) are similar to those with a 228,000-cfs flow. The effects of the current and attention required were much higher than during the lower flow, as would be expected, but the difference from the existing condition to the plan condition was small. The effects of current and attention required for the plan were rated higher than for the existing condition for the downstream runs, but were lower or almost equal in the upstream runs.

## Composite ship track plots

A complete set of the composite ship track plots for the test conditions is presented in Plates 89-100. The minimum distance between the tow and traffic ship for each individual run is presented in Table 3. Some runs indicate no recorded distance between the vessels. If the vessels did not close within approximately 2,000 ft, the distance was not recorded; therefore if no distance is indicated, the vessels never got within 2,000 ft of each other.

**Downstream runs, 228,000-cfs flow.** The composite track plots for the existing and plan conditions (Plates 89 and 90) show the pilots used basically the same line in passage, with or without the dikes, with the exception of one pilot who cut outside the ship buoy at the lower ship ranges during the existing condition and one pilot who ran the left descending bank down to the crossing with the dike plan. Most pilots stayed close to midchannel and allowed the traffic ship to pass on their port side before they reached the fleeting area, then ran fairly close to the left edge of the channel through the

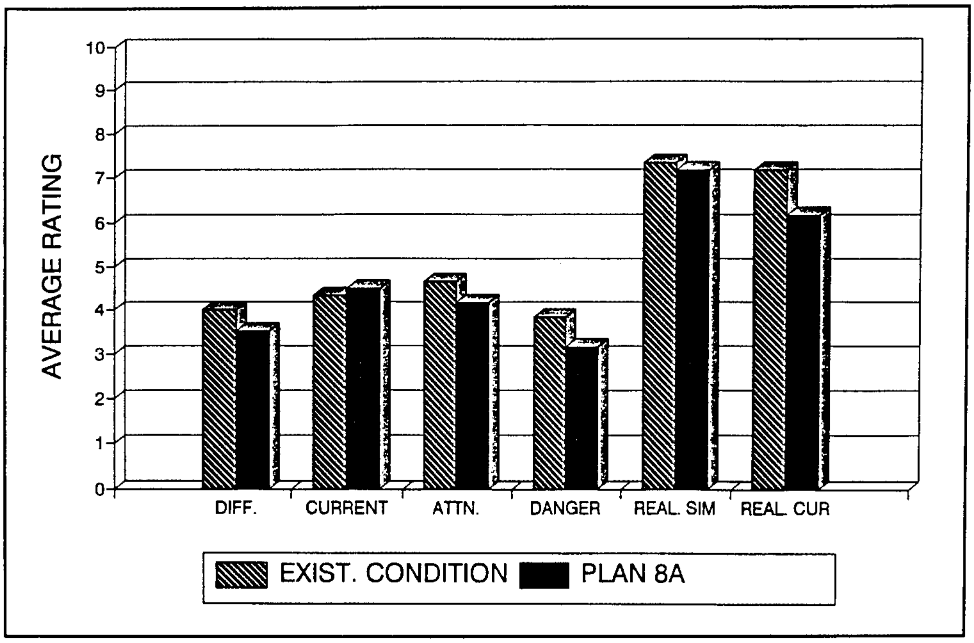



Figure 20. Large-tow pilots' ratings, 228,000-cfs flow, downstream runs

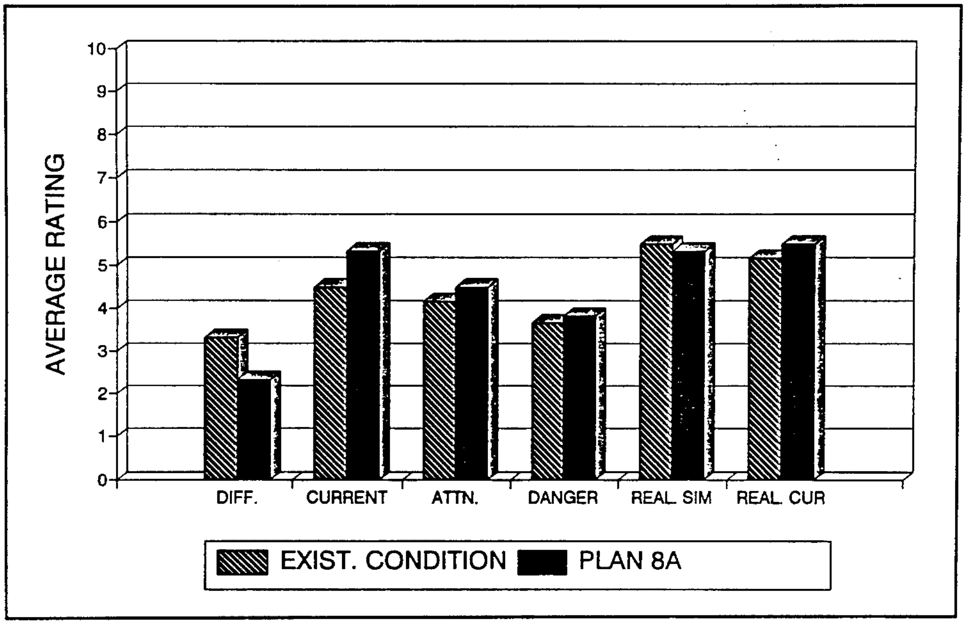



Figure 21. Large-tow pilots' ratings, 228,000-cfs flow, upstream runs

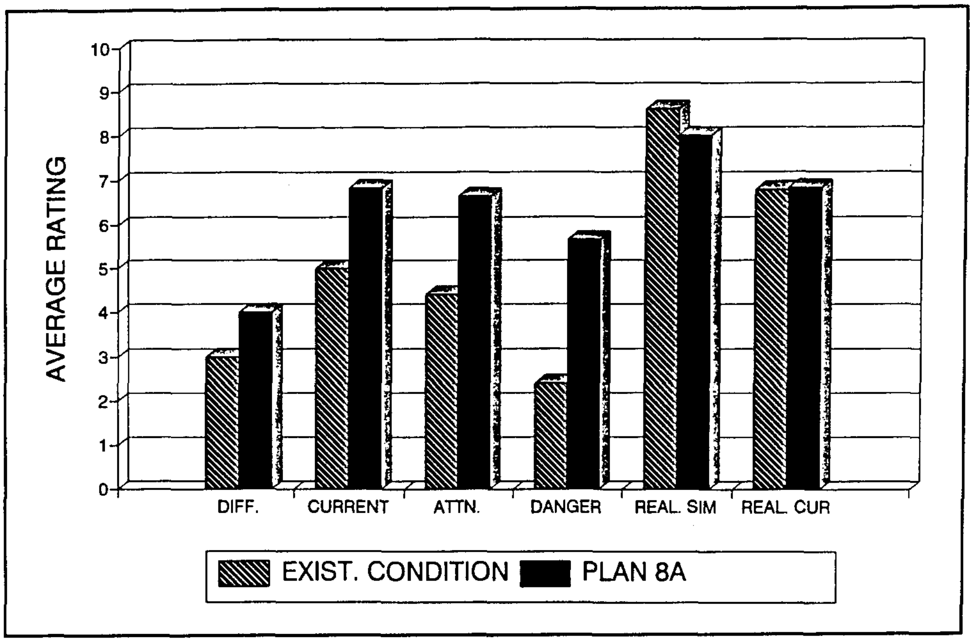



Figure 22. Large-tow pilots' ratings, 670,000-cfs flow, downstream runs

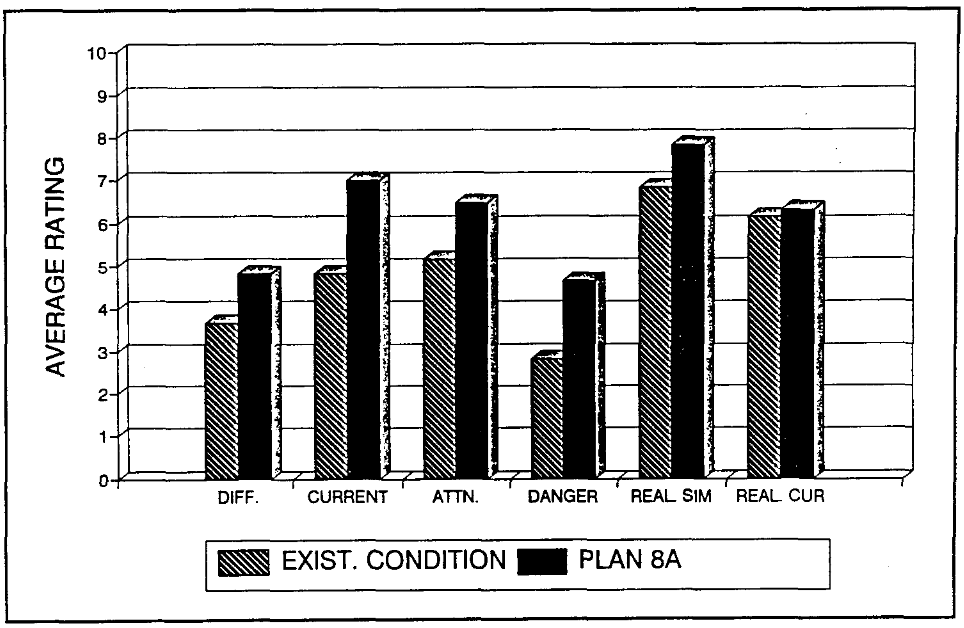



Figure 23. Large-tow pilots' ratings, 670,000-cfs flow, upstream runs

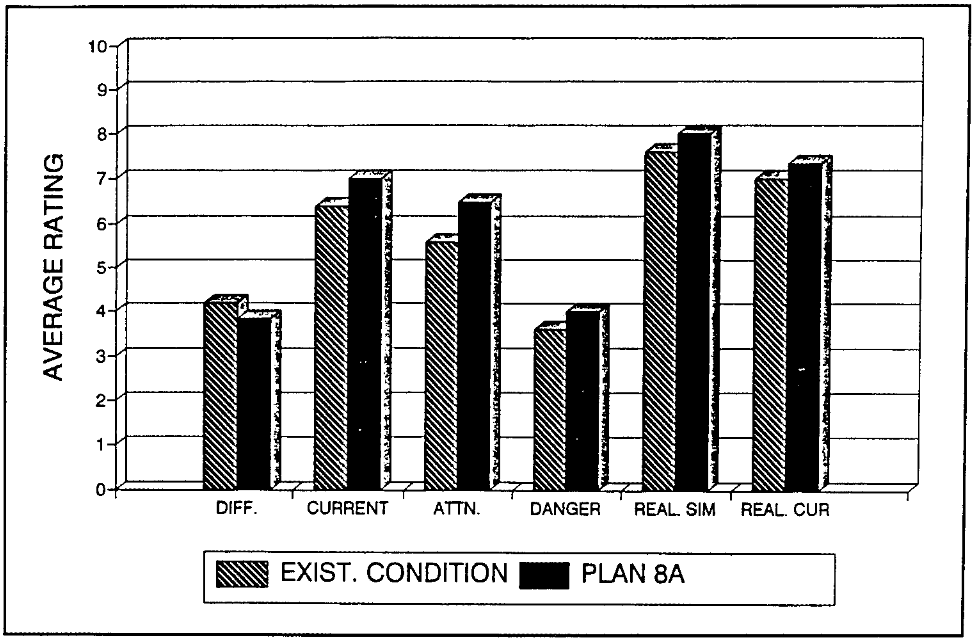



Figure 24. Large-tow pilots' ratings, 1,500,000-cfs flow, downstream runs

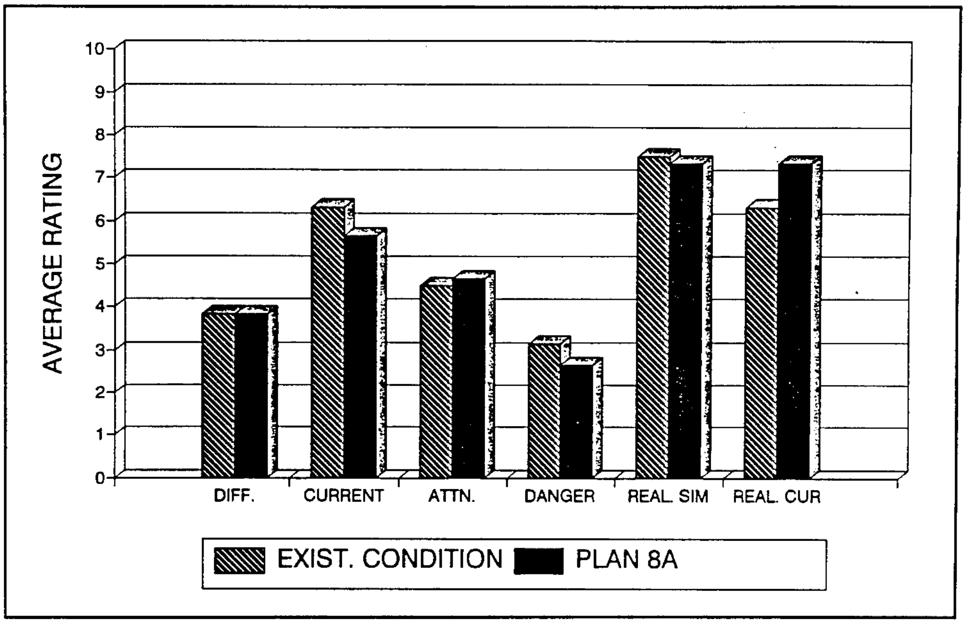



Figure 25. Large-tow pilots' ratings, 1,500,000-cfs flow, upstream runs

crossing and the bendway, coming back to midchannel as they completed their runs.

**Upstream runs, 228,000-cfs flow.** The plots for both existing and plan conditions (Plates 91 and 92) show the pilots using the same strategy. Most tracks tended to run up the left side of the channel through the bend then cross quickly to the right side of the channel and stay close to the right side up to opposite the upper ship ranges. One pilot varied from this pattern by holding close to the ends of the dikes, then crossing to the right side of the channel between the fleeting area and Dravo Dock. One pilot allowed the tow to get very near the right descending bank downstream of the lower ship ranges. This was probably due to indecision on where to have his tow when meeting the traffic ship. This pilot crossed back toward the left side of the channel and collided with the traffic ship at the lower ship ranges. The traffic ship is obscured for many of these runs due to overlapping track plots but can be observed clearly on individual run plots.

**Downstream runs, 670,000-cfs flow.** The track plots for both existing and plan conditions (Plates 93 and 94) show wide variations in how the pilots chose to run, even within the same condition. During the existing condition, the pilots used different strategies on where they ran. Four of the pilots chose to run the bend outside the ship buoys and come back into the main channel below Dow Dock. The pilots also varied in whether they allowed the traffic ship to overtake and pass them. Five pilots held up and allowed the ship to pass either upstream of or within the crossing, but the other pilot ran full ahead and outran the ship, passing through the test reach before the ship could catch him. With the dikes in place, the tracks tended to be more uniform until the tows passed the last dike. After that point, four of the pilots remained in the main channel and two came in under the dike and ran outside the ship buoys before coming back into the main channel below Dow Dock. Again, the pilots varied on whether they allowed the ship to pass or not. Only two pilots allowed the ship to pass before reaching the crossing, and the other four did not.

The higher pilot ratings (Figure 22) for difficulty of run, effects of current on the tow, amount of attention required, and danger of hitting an object may be due to the amount of navigable channel being reduced by the dikes. The pilots were forced to follow a more uniform path through the crossing due to the dikes compared with the existing condition, but the track plots indicate no particular difficulty or problem associated with the dikes. The pilots normally chose to drive the tow close to the dike markers. Another factor that may have influenced the pilots' ratings was that more chose to stay in the main channel and pass by Dow Dock in the plan than with the existing condition. The pilots who stayed in the main channel experienced more effects from the currents and took longer to break their "slide" (lateral motion). This made the danger of hitting a buoy or vessels tied up at Dow Dock and the attention required to avoid a collision much greater than during the existing condition. The two pilots who went around the last dike and

outside the ship buoys experienced some of the "slide" but had more room to maneuver, and therefore, a larger margin of safety.

**Upstream runs, 670,000-cfs flow**. The tracks with the existing condition (Plate 95) are very different from those with the plan condition (Plate 96). In the existing condition, all the pilots ran up the left descending bank below the island to avoid the current. As they passed the buoy marking the downstream end of the island, they turned, going outside the ship buoy and proceeding up the left descending bank. Five of the pilots stayed along the left bank until they got to the fleeting area, then four crossed to the right bank and completed their runs. The fifth pilot chose to stay on the left bank and ran it all the way up to the completion point. One pilot crossed from left to right bank at the downstream end of the channel crossing and stayed on the right bank. With the plan condition, the pilots used the same pattern as with the existing condition up to the downstream end of the island. At this point, four of the pilots chose to go outside the buoy line, coming up along the island and driving toward the end of the last dike. The other two pilots chose to stay within the main channel and drove up along the buoy line. The four pilots who went outside the buoys met and passed the traffic ship with little difficulty. The two pilots who stayed within the marked channel also met and passed successfully, but were forced to crowd the buoys to allow the ship to pass. After all pilots passed the last dike downstream, they all moved in along the right descending bank and held to it all the way up to the completion point.

The higher pilot ratings for difficulty, current effect, attention, and danger likely come from the difficulties encountered by the pilots going outside the buoys passing the island then coming around the last dike. The pilots who remained in the channel had difficulty in meeting and passing the traffic ship without striking the buoys. Before the pilots reached the foot of the island and after they had passed the last dike downstream, the tracks show they had little difficulty. Another factor in the ratings may have been that the pilots lost their option of driving up the left bank after passing the island, forcing them to drive into the heavier currents off the ends of the dikes.

**Downstream runs, 1,500,000-cfs flows.** The existing condition runs (Plate 97) show the pilots used much of the available channel for their transits through the reach. Most pilots tended to stay near the left bank through the crossing and bend and then come out to midchannel below the island. One pilot chose to stay in the ship channel through the crossing and bend, bringing him much closer to Dow Dock than any of the other pilots. The track plots show no indication of any control problems. With the plan condition (Plate 98), the tracks are much more uniform, with the pilots passing just off the ends of the dikes, then turning quickly after passing the last dike, bringing them along the inside of the bend and passing near the foot of the island. Again, no indications of control problems are evident. None of the pilots chose to let the traffic ship overtake and pass. In all runs, the tow stayed well ahead of the ship completely through the simulation.

The pilot evaluations of the runs show that the pilots rated the plan condition slightly higher than the existing condition for current effect, danger of striking an object, and attention required. The averages of current effects and attention required for the plan condition are almost identical to the ratings given for the 670,000-cfs flow. The major difference is in danger of striking an object, where the pilots rated the 670,000-cfs flow much higher than the 1,500,000-cfs flow for the plan condition. One explanation of the lower danger rating on the higher discharge flow might be that there were no channel buoys in the 1,500,000-cfs-flow scenarios. The track plots show that the pilots used the channel where the buoys had been in the 670,000-cfs scenarios to make their passage. The difficulties of navigating around the bend and avoiding the buoys in the 670,000-cfs scenarios may have been a factor in the higher danger ratings.

**Upstream runs, 1,500,000-cfs flow.** As with the upbound 670,000-cfs-flow scenarios, the pilots were forced to use a very different strategy to make their transits. For the existing condition (Plate 99), all of the pilots came up the left bank, around the foot of the island, then up against the left bank. Most of the pilots stayed on the left bank till they approached the fleeting area, then moved cross-channel to the right bank and completed their runs. One pilot chose to cross from left to right bank near the downstream end of the crossing, then came up along the right bank. With the plan condition (Plate 100), the pilots still approached the bend along the left bank. Four of the pilots went around the toe of the island then drove toward the end of the last dike downstream. The other two pilots turned and went through the chute between the island and the left bank, then drove toward the end of the last dike. The pilots varied when they crossed toward the right bank from just off the end of the last dike to just off the third dike. All pilots, after crossing to the right bank, stayed on the right bank through the remainder of their runs.

The pilots rated the plan condition to be almost the same as the existing condition for all questions. The track plots indicate no particular problems in navigating the reach with the dikes compared to without, which reflects in the pilots' ratings.

## Statistical Analysis

During each run, the control, positioning, and orientation parameters of the tow were recorded every 5 seconds. These parameters included position, speed, rpm of each propeller, and rudder angle. All statistical parameters are plotted against distance along track. The distance along track is calculated by projecting the position of the tow center of gravity perpendicular to the center line of the channel and is measured from the beginning of the center line (Figure 11).

For all parameters, the statistical analysis is presented as a mean of means within a sample channel section. A 500-ft channel section was used.

This means that for each individual run, each parameter was averaged over 500 ft, and these means were averaged over all runs under a given condition, thus a mean of the means.

### Rudder angle

Steering and flanking rudders used for the existing and plan conditions are plotted in percent of maximum. Discussion of these plots will be by flow condition.

**228,000-cfs flow.** Use of rudder for the downstream and upstream runs (Plates 101 and 102) shows little difference in the amounts of rudder required to navigate the reach. The upstream runs tended to have a less erratic use of rudder with the dikes compared with the existing condition.

**670,000-cfs flow.** The rudder plot for downstream (Plate 103) shows little difference in rudder use from existing to plan condition, except for the large use of rudder during the plan runs near the lower ship ranges. This is due to the pilots turning to port below the last dike to come across the inside of the bend. The upstream plot (Plate 104) shows less rudder used as the tow comes along the Dow Dock. During the existing condition, all pilots turned across the toe of the island and came up along the left bank. During the plan condition, the pilots split with some going up along the island and the others staying in the main channel inside the ship buoys, requiring less use of rudder. After this point, there is little difference in rudder usage from one condition to the other.

**1,500,000-cfs flow.** The downstream plot (Plate 105) shows little differences in the rudder used. The flanking rudder was used by two pilots during their runs. This caused the average amount of steering rudder to be less than for the existing condition. The flanking rudder use was not for maintenance of control but was "experimentation" by the pilots to see if the tow flanked as they expected. The upstream plot (Plate 106) shows a similar occurrence to the upstream runs of the 670,000-cfs flow. More rudder was used during the existing condition near Dow Dock than during the plan condition. Again, during the existing condition, the pilots turned at the toe of the island and went up along the left bank. During the plan condition, they turned at the toe of the island but went toward the end of the last dike, requiring less rudder. After this turn, rudder usage was about the same for both conditions.

### Engine rpm and speed

Engine rpm for each engine is plotted in percent of maximum rpm. For the 5,600-hp boat, there are two engines and for the 10,500-hp boat, three engines. In most cases, rpm for the engines was almost identical. Occasionally, the pilots failed to use the center engine of the 10,500-hp boat

for the full run. Individual engine rpm plots will help point this out. Discussion of these parameters will be grouped by flow condition. Downstream flows are plotted from left to right. Upstream flows are plotted from right to left.

**228,000-cfs flow.** The plot for the downstream runs (Plate 107) shows that full power was used for most of the runs, except during the first 13,000 ft of the track, where the pilots were slowing to allow the ship to pass, and near the end of the runs. There is no apparent reason for slowing the engines near the end of the run except that one pilot must have pulled the throttles back shortly before reaching the ending point, thinking he had reached the end. Slightly better speed was achieved with the dikes in place than with the existing condition. The upstream plots (Plate 108) show full throttle for all engines except for the center engine. One pilot failed to bring the center engine out of neutral until well into the run. This accounts for the large drop in the mean rpm for the center engine and some of the drop in speed at the beginning of the run. Speed was slightly higher for the existing condition for most of the track length.

**670,000-cfs flow.** The downstream plots (Plate 109) show the wide variance in where the pilots allowed the traffic ship to pass. Some chose to slow down early and let it pass, others later on before reaching the crossing, and some outran the ship and had no passing. The existing condition runs tended to have the ship passing earlier in the runs, and the plan conditions slowed before the crossing and allowed passing. The large drop in rpm near Dow Dock is due to the "experimentation" by one pilot with flanking. Comparing the rudder plot of this condition (Plate 103) with the rpm plot, it can be noted that the use of flanking rudders and the large drop in rpm coincide in their position along the track line. The pilot using the flanking rudder also put the engines in full reverse, causing the mean of the rpm at this point for all the downstream runs to be much lower. The speed during the plan condition runs was considerably higher than with the existing condition. This increase in speed may have influenced the pilots' evaluation ratings of the runs. The higher speed increased the amount of "slide" they experienced in the bend upstream of Dow Dock and reduced their reaction time, possibly causing them to rate the plan condition higher for difficulty, current effect, attention required, and danger of striking an object. The upstream run (Plate 110) shows all pilots using maximum engine rpm for the entire run. One pilot failed to bring the center engine out of neutral, and actually had the engine turning slowly in reverse for over half of his run. Since this could adversely affect the mean of the speeds, this pilot's run was dropped and the mean of the other five pilots used for this plot. Speed during the plan condition was from 1.5 to 2.0 mph slower than the existing condition for most of the run. The only places the speed was relatively close to the base condition were early in the run before turning at the toe of the island and near the end of the run as the tows ran up the right bank line.

**1,500,000-cfs flow.** The downstream run plots (Plate 111) again show large differences in the pilots' operation technique. During the existing

condition run, one pilot chose to start flanking almost immediately after the start of his run. He pulled the engines to full reverse, which lowered the mean of the engine rpm considerably. After realizing later that he could outrun the traffic ship, he brought the engines full ahead. During the plan condition runs, one pilot decided to try flanking. This accounts for the large drop in engine rpm near Dow Dock. Later, near the end of the run, pilots also again used a flanking maneuver during the existing and plan conditions. The speed plot shows the plan condition to be faster to about the lower ship ranges, then slower to below Dow Dock, then about the same as the existing condition. This probably is deceiving since one pilot chose to flank through the upper half of his run, cutting the speed of passage for his run and the mean of all the runs. The same is true for the flanking during the plan condition, which cut the speed back on the mean. Removing the pilot's runs with flanking would leave only three runs to take means. Speed of the plan condition would probably be very close to that of the existing condition if all the pilot runs had been made with engines full ahead for the entire run. All the upstream runs (Plate 112) were made with throttles full ahead. The speed for the plan condition is slightly over 1 mph better than the existing condition from just downstream of Dow Dock to the lower ship ranges (the end of the last dike downstream). Upstream of the last dike, the plan condition runs are slightly faster than the existing.

## Conclusions

Pilot evaluations rated the plan condition with the 670,000-cfs flow as being much more difficult than the existing condition. Track plots of the pilots' runs and analysis of the tow parameters do not reveal any greater difficulties, except for the point that one pilot made that the buoys in the bendway upstream of Dow Dock would probably not be there with this flow condition. These buoys being in place during the simulation of this flow condition may have placed obstacles in the channel that would not normally have been, therefore making the run more difficult. Had these buoys not been in place during this flow scenario, the pilots would have been able to run the bendway as they did with the 1,500,000-cfs-flow condition. The pilots rated all other flow conditions for the plan scenarios to be almost the same as with the existing.

Examination of the pilot ratings, track plots, tow parameters, and pilot comments reveals that under most conditions, the dike system, as proposed in Plan 8A optimized, will not adversely affect safety or operation of the large tows in the test reach by consent between pilots. Passing of vessels (ships and tows) will probably be restricted in the test reach by consent between pilots. Certain flow conditions, such as the 670,000-cfs flow, will probably be more difficult to navigate but not excessively.

# 5 Conclusions and Recommendations

## Conclusions

### Ships

The pilots commented that the dikes for either Plans 5A or 8A were navigation hazards. They rated individual runs for the dike plans to be slightly more difficult than the existing condition with Plan 8A being slightly more difficult than Plan 5A. Track plots and parameter plots indicate a slight difference in difficulty for operation with either of the dike plans compared with the existing condition, but not significantly higher.

### Small tows

Plan 5A will increase operational difficulty slightly, but not significantly so. Upbound traffic will be slower with Plan 5A than with the existing condition, but slightly faster going downstream. Meeting and passing of the tow with traffic vessels can still be accomplished with minimal increase in difficulty. Plan 8A would significantly decrease the upstream transit speed with the flow condition tested.

### Large tows

The pilots commented that the 670,000-cfs-flow condition with Plan 8A was much more difficult than with the existing condition. Track plots and parameter plots do not indicate any apparent increase of difficulty. One of the pilots' comments about placement of buoys in Missouri Bend with this flow condition and the difficulty in avoiding them might give insight into the perception of greater difficulty. The other flow scenarios for the existing condition and Plan 8A were rated almost identical.

## Recommendations

The following recommendations are made:

*a.* Shallow-draft tows should be allowed to transit over the dikes when there is sufficient depth over them.

*b.* Guidelines should be established on meeting and passing procedures for vessels within the Redeye Crossing during river stages that would require tows and ships to be within the deep-water channel with either dike plan in place.

*c.* Further testing should be performed with small tows if Plan 8A is adopted, due to the limited testing performed with this plan and the drastically reduced speeds for upbound transit with the one flow condition tested.

**Table 1**
**Minimum Distance from Ship to Tow**

| Pilot | Flow 1,000 cfs | Direction | Distance, ft, for Plan: Existing | 5A Optimized | 8A Optimized |
|---|---|---|---|---|---|
| C | 228 | Upstream | 1,934 | 1,348 | 1,536 |
| D | | | 2,247 | 1,272 | 1,382 |
| E | | | 1,823 | 1,376 | 1,352 |
| F | | | 2,146 | 1,215 | 1,283 |
| G | | | 2,493 | 1,425 | 1,523 |
| H | | | 2,172 | 1,401 | 1,215 |
| C | | Downstream | 981 | 988 | 1,010 |
| D | | | 1,214 | 911 | 1,063 |
| E | | | 1,159 | 994 | 902 |
| F | | | 960 | 960 | 937 |
| G | | | 894 | 1,025 | 944 |
| H | | | 1,159 | 1,074 | 1,009 |
| C | 450 | Upstream | 1,950 | 1,485 | - |
| D | | | 1,977 | 1,403 | - |
| E | | | 1,627 | 1,447 | - |
| F | | | 1,822 | 1,648 | - |
| G | | | 2,033 | 1,593 | - |
| H | | | 1,878 | 1,566 | - |
| C | | Downstream | 1,173 | 941 | - |
| D | | | 995 | 787 | - |
| E | | | 871 | 830 | - |
| F | | | 956 | 1,267 | - |
| G | | | 1,724 | 1,219 | - |
| H | | | 1,138 | 1,078 | - |
| C | 530 | Upstream | 1,848 | - | 1,454 |
| D | | | 1,701 | - | 1,323 |
| E | | | 1,789 | - | 1,498 |
| F | | | 1,755 | - | 1,393 |
| G | | | 1,772 | - | 1,352 |

(Continued)

Note: - = No test performed.

Table 1 (Concluded)

| Pilot | Flow 1,000 cfs | Direction | Distance, ft, for Plan: Existing | 5A Optimized | 8A Optimized |
|---|---|---|---|---|---|
| H | 530 (Cont) | Upstream (Cont) | 2,535 | - | 1,433 |
| C | | Downstream | 787 | - | 999 |
| D | | | 1,307 | - | 1,027 |
| E | | | 792 | - | 1,154 |
| F | | | 846 | - | 965 |
| G | | | 1,149 | - | 1,111 |
| H | | | 1,239 | - | 1,081 |
| C | 1,500 | Upstream | 1,750 | 1,340 | 1,431 |
| D | | | 1,614 | 1,451 | 1,289 |
| E | | | 2,039 | 1,383 | 1,465 |
| F | | | 1,794 | 1,527 | 1,618 |
| G | | | 2,479 | 1,212 | 1,373 |
| H | | | 1,775 | 1,356 | 1,436 |
| C | | Downstream | 498 | 667 | 681 |
| D | | | 920 | 837 | 569 |
| E | | | 891 | 928 | 867 |
| F | | | 965 | 858 | 859 |
| G | | | 1,117 | 1,037 | 736 |
| H | | | 999 | 723 | 1,060 |

## Table 2
## Minimum Distance from Small Tow to Ship

| Pilot | Flow 1,000 cfs | Direction | Distance, ft, for Plan: Existing | 5A Optimized | 8A Optimized |
|---|---|---|---|---|---|
| I | 228 | Upstream | 253 | 539 | - |
| J | | | 293 | 527 | - |
| K | | | 559 | 517 | - |
| L | | | 196 | 547 | - |
| I | | Downstream | 768 | 1,132 | - |
| J | | | 888 | 1,070 | - |
| K | | | 50[a] | 872 | - |
| L | | | 320 | 1,336 | - |
| I | 450 | Upstream | 503 | 674 | - |
| J | | | 555 | 1,054 | - |
| K | | | - | 642 | - |
| L | | | 1,564 | - | - |
| I | | Downstream | 303 | 596 | - |
| J | | | 306 | 541 | - |
| K | | | 1,061 | 1,760 | - |
| L | | | 104[a] | 940 | - |
| I | 670 | Upstream | 492 | - | 2,514 |
| J | | | 2,359 | - | 1,819 |
| K | | | 1,725 | - | 635 |
| L | | | 2,607 | - | 2,187 |
| I | | Downstream | 2,197 | - | 491 |
| J | | | 490 | - | 666 |
| K | | | 208 | - | 1,171 |
| L | | | 972 | - | 1,896 |
| I | 1,500 | Upstream | 3,055 | 2,614 | - |
| J | | | 2,593 | 1,826 | - |
| K | | | 2,540 | 2,139 | - |
| L | | | 2,831 | 3,108 | - |
| I | | Downstream | 852 | 728 | - |

(Continued)

Note: - = No test performed.
[a] Vessels collided.

| Table 2 (Concluded) | | | | | |
|---|---|---|---|---|---|
| | | | Distance, ft, for Plan | | |
| **Pilot** | **Flow 1,000 cfs** | **Direction** | **Existing** | **5A Optimized** | **8A Optimized** |
| J | 1,500 (Cont) | Downstream | 929 | 1,573 | - |
| K | | | 744 | 932 | - |
| L | | | 935 | 501 | - |

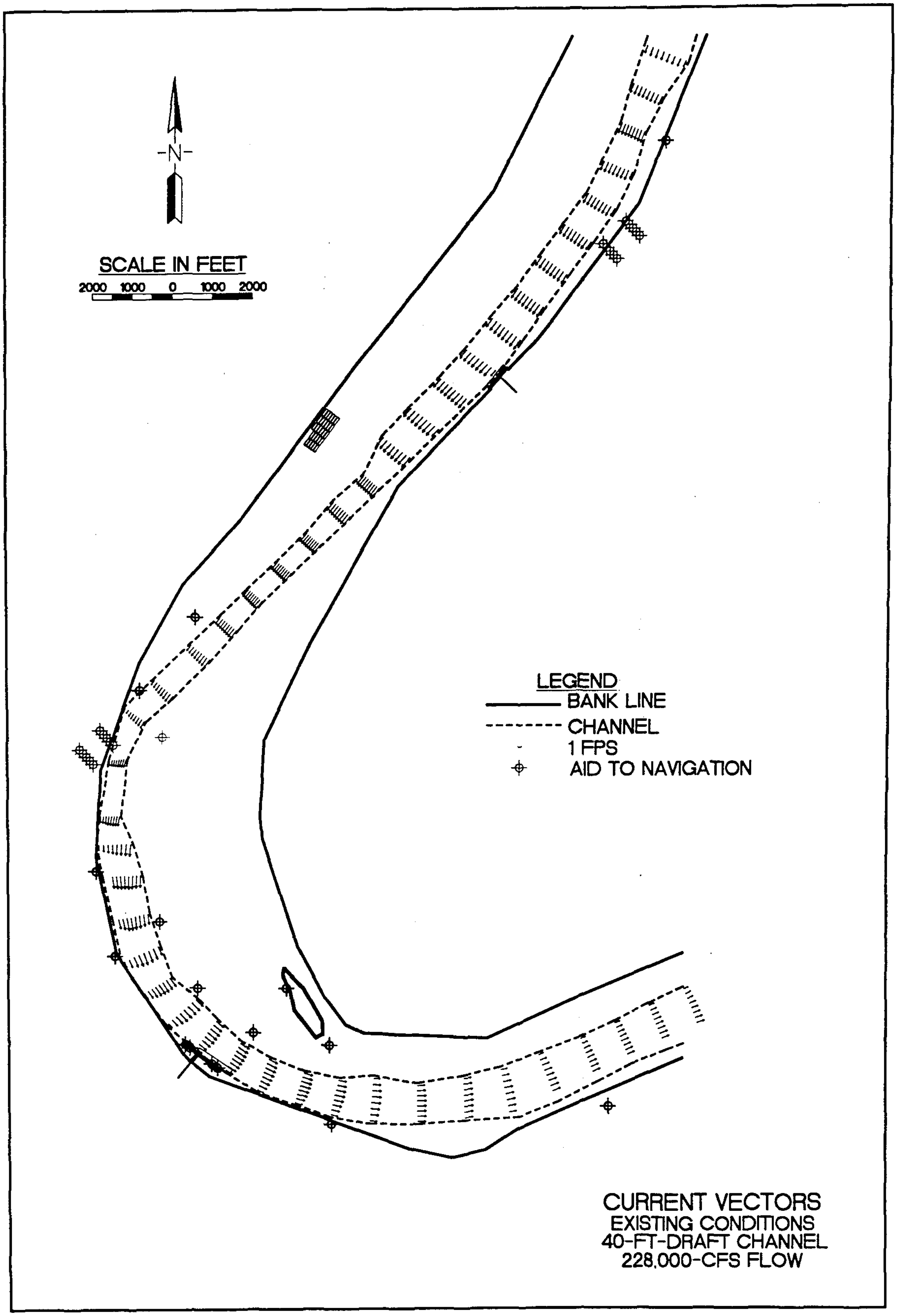
**Table 3**
**Minimum Distance from Large Tow to Ship**

| Pilot | Flow 1,000 cfs | Direction | Distance, ft, for Plan: Existing Condition | Distance, ft, for Plan: 8A Optimized |
|---|---|---|---|---|
| R | 228 | Downstream | 555 | 470 |
| S | | | 525 | 455 |
| T | | | 861 | 331 |
| U | | | 521 | 1,677 |
| V | | | 435 | 254 |
| W | | | 504 | 460 |
| R | | Upstream | 654 | 602 |
| S | | | NA | 531 |
| T | | | 66[a] | 567 |
| U | | | 536 | 584 |
| V | | | 452 | 371 |
| W | | | 86[a] | 612 |
| R | 670 | Downstream | 1,303 | NA |
| S | | | 595 | NA |
| T | | | 368 | 576 |
| U | | | 986 | NA |
| V | | | 910 | NA |
| W | | | 401 | 632 |
| R | | Upstream | NA | 817 |
| S | | | NA | NA |
| T | | | NA | 989 |
| U | | | NA | 528 |
| V | | | NA | 546 |
| W | | | NA | NA |
| R | 1,500 | Downstream | NA | NA |
| S | | | NA | NA |
| T | | | 1,792 | NA |
| U | | | 895 | NA |
| V | | | NA | NA |

(Continued)

Note: NA = No recorded distance (never closed to < 2,000 ft)
[a] Vessels collided.

| Table 3 (Concluded) | | | | |
|---|---|---|---|---|
| | | Distance, ft, for Plan | | |
| Pilot | Flow 1,000 cfs | Direction | Existing Condition | 8A Optimized |
| W | 1,500 (Cont) | Downstream | 588 | NA |
| R | | Upstream | NA | 846 |
| S | | | NA | 933 |
| T | | | NA | 1,079 |
| U | | | NA | 696 |
| V | | | NA | 319 |
| W | | | NA | NA |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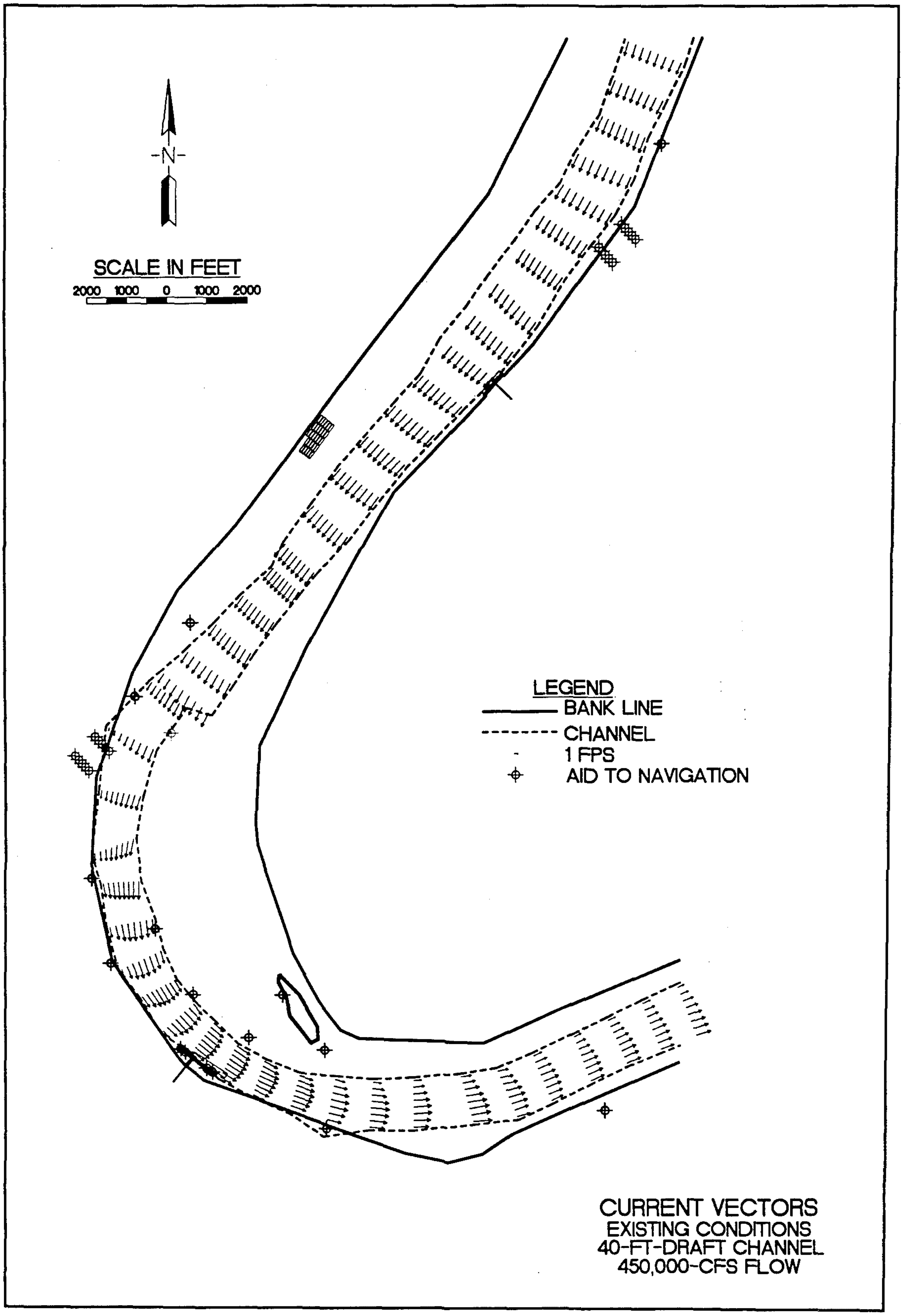
CURRENT VECTORS
EXISTING CONDITIONS
40-FT-DRAFT CHANNEL
228,000-CFS FLOW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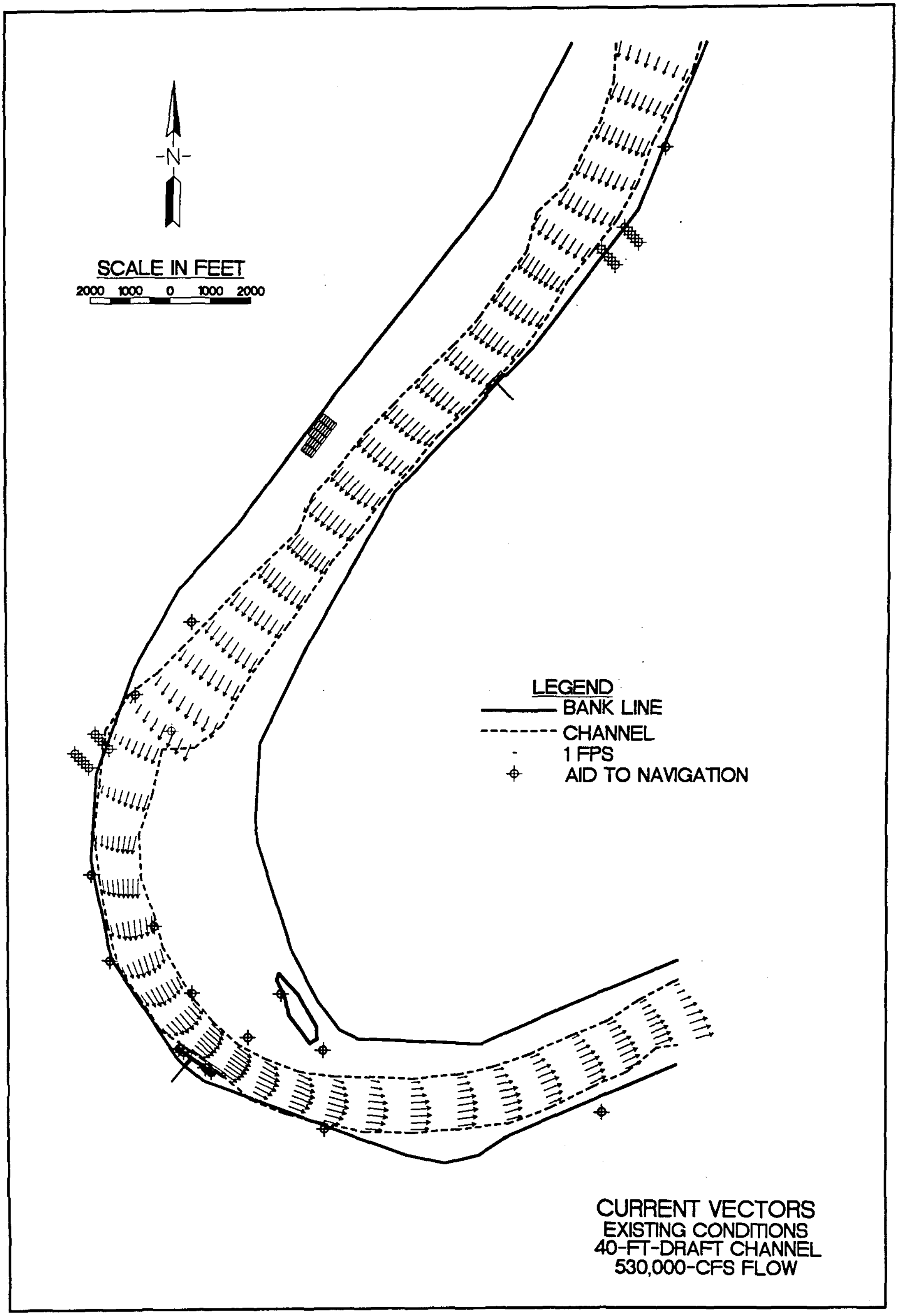
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AID TO NAVIGATION
CURRENT VECTORS
EXISTING CONDITIONS
40-FT-DRAFT CHANNEL
450,000-CFS FLOW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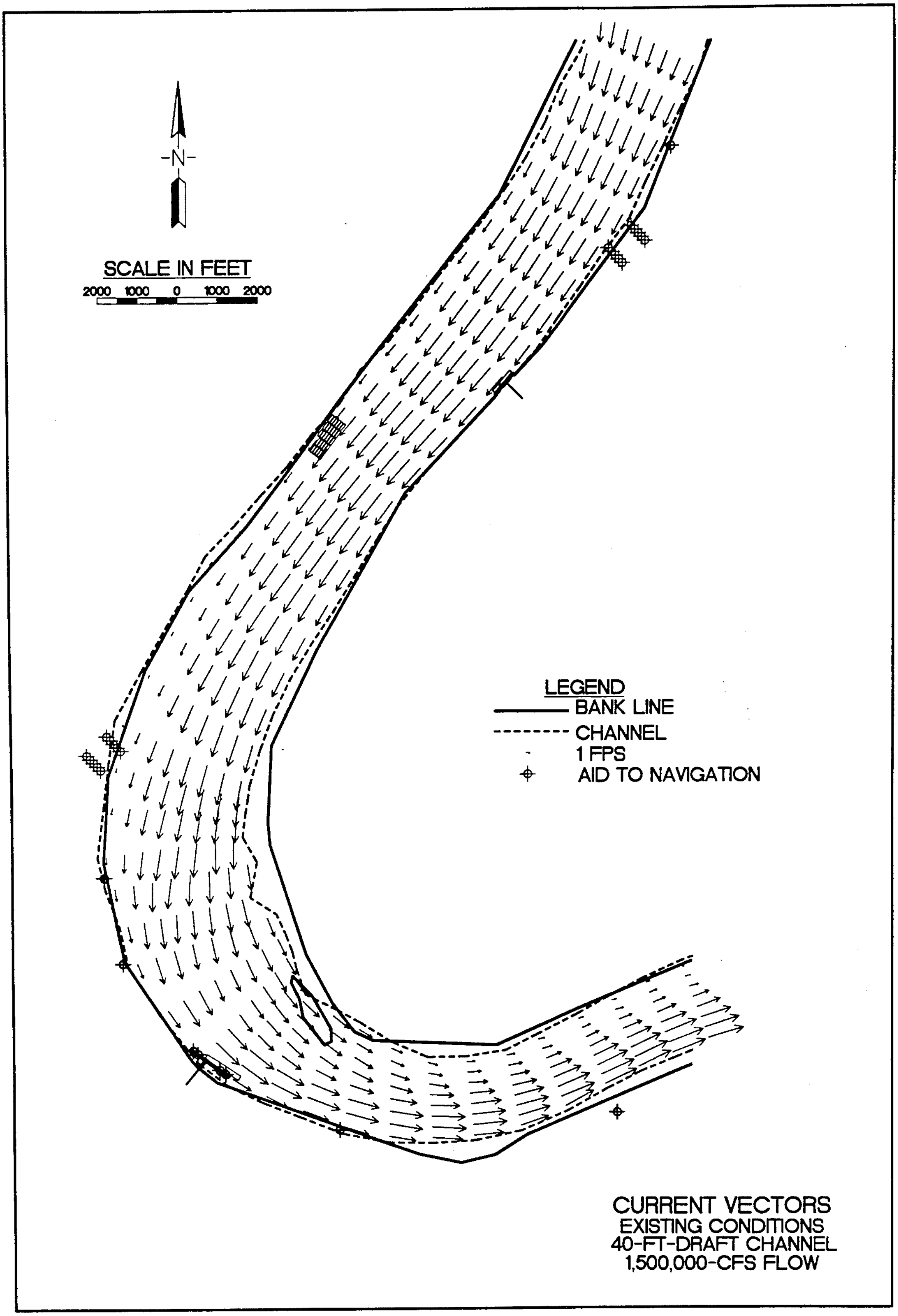
CHANNEL
1 FPS
AID TO NAVIGATION
CURRENT VECTORS
EXISTING CONDITIONS
40-FT-DRAFT CHANNEL
530,000-CFS FLOW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SCALE IN FEET
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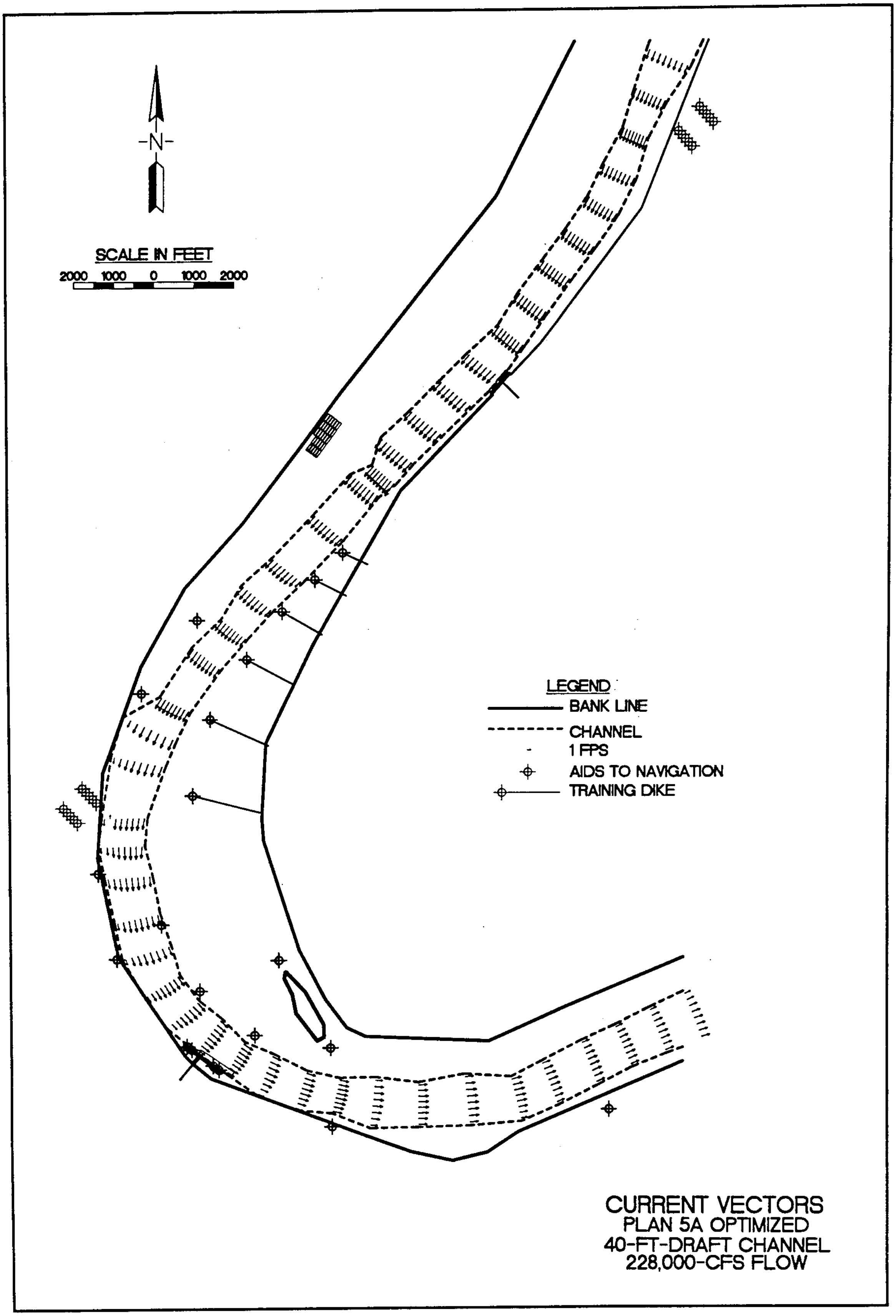
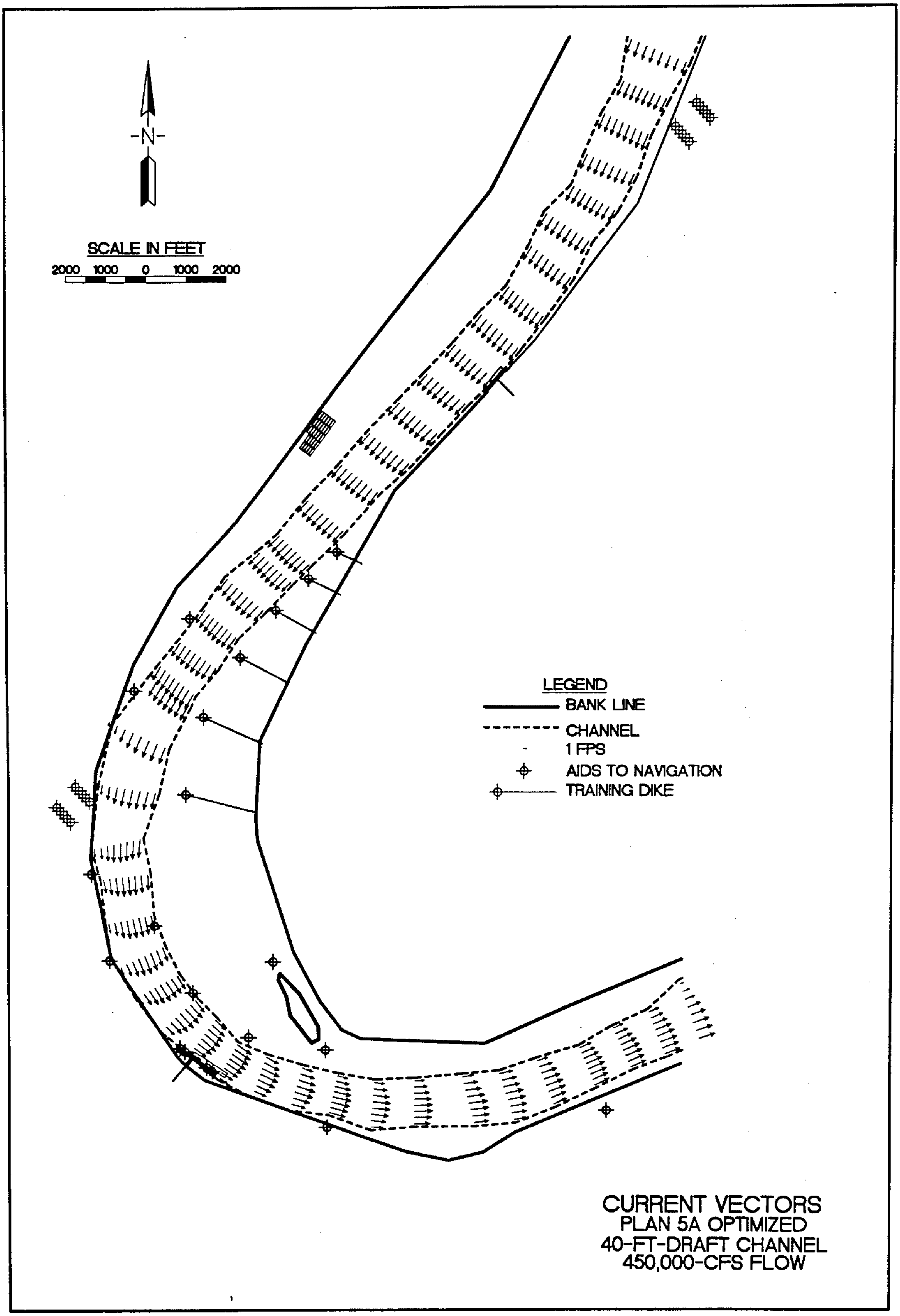
BANK LINE
CHANNEL
1 FPS
AID TO NAVIGATION
CURRENT VECTORS
EXISTING CONDITIONS
40-FT-DRAFT CHANNEL
1,500,000-CFS FLOW




CURRENT VECTORS
PLAN 5A OPTIMIZED
40-FT-DRAFT CHANNEL
228,000-CFS FLOW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SCALE IN FEET
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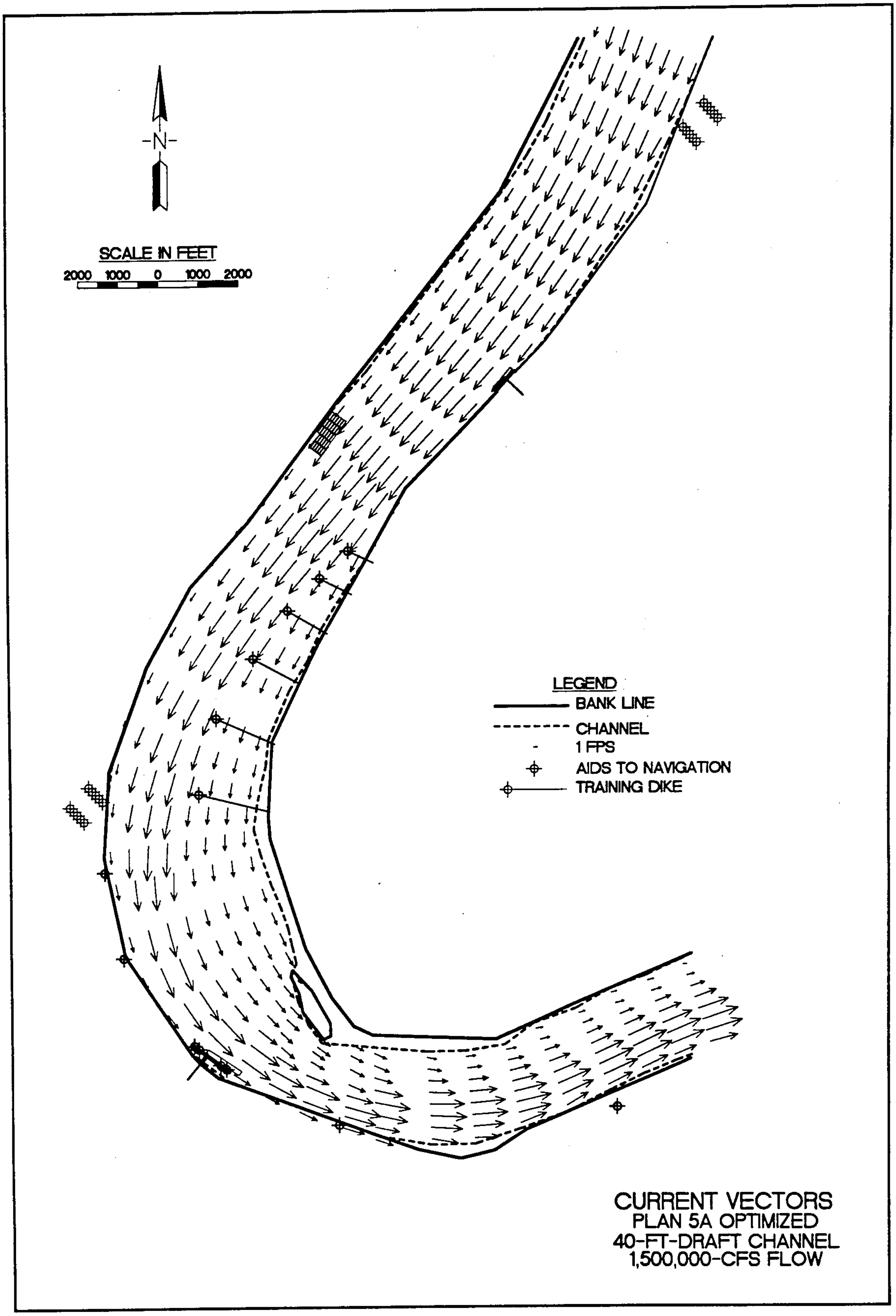
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 5A OPTIMIZED
40-FT-DRAFT CHANNEL
450,000-CFS FLOW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SCALE IN FEET
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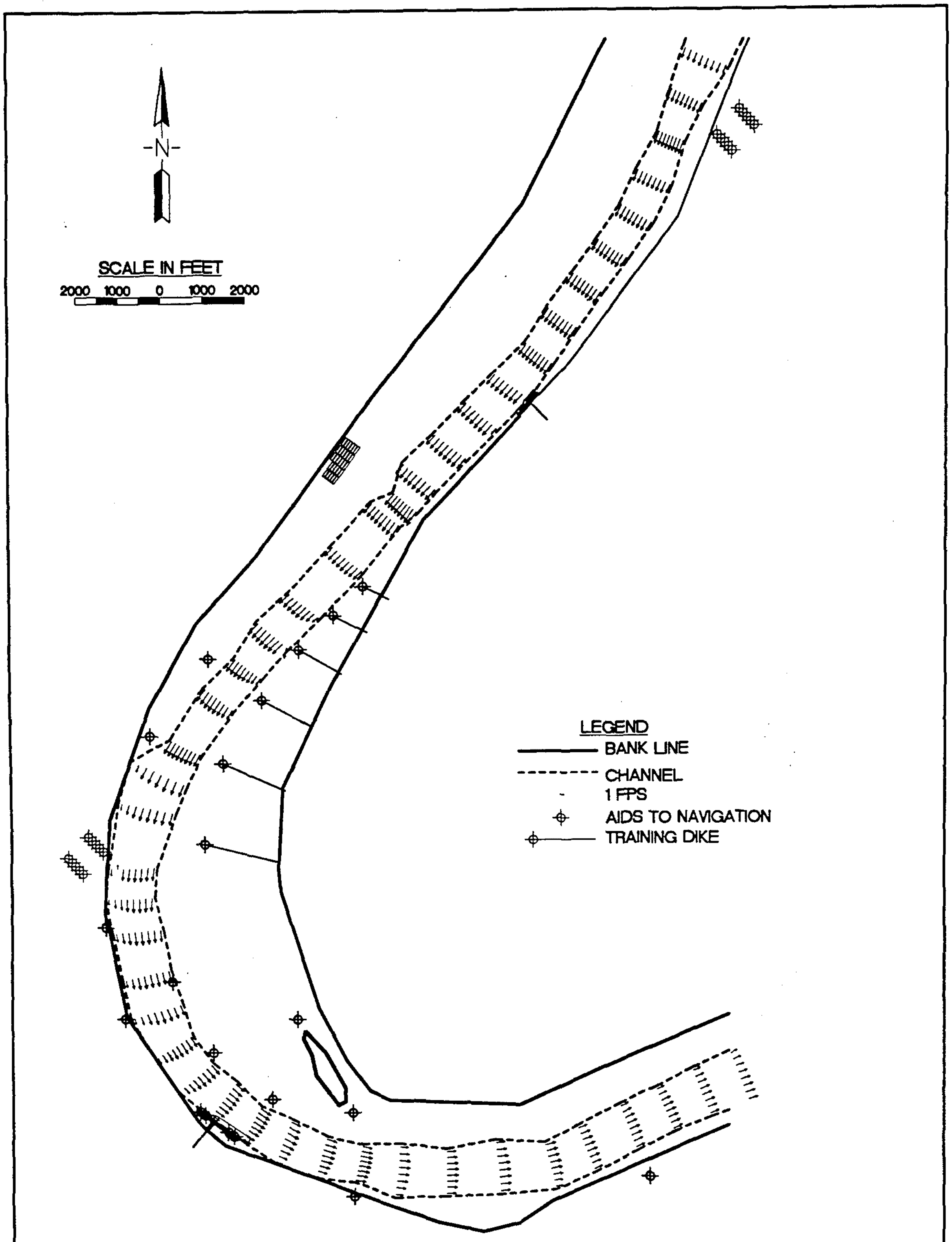
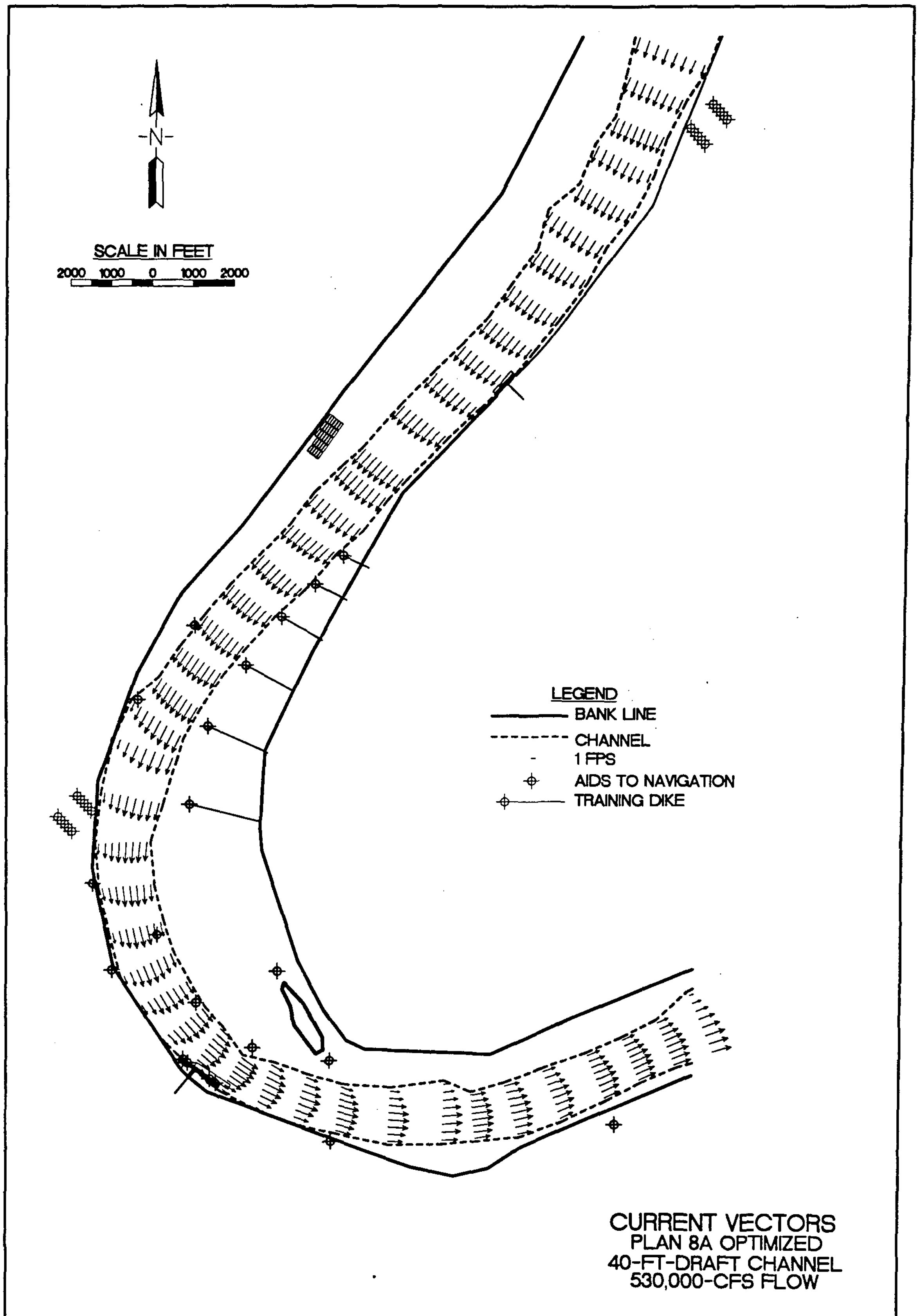
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 5A OPTIMIZED
40-FT-DRAFT CHANNEL
1,500,000-CFS FLOW




CURRENT VECTORS
PLAN 8A OPTIMIZED
40-FT-DRAFT CHANNEL
228,000-CFS FLOW

Plate 8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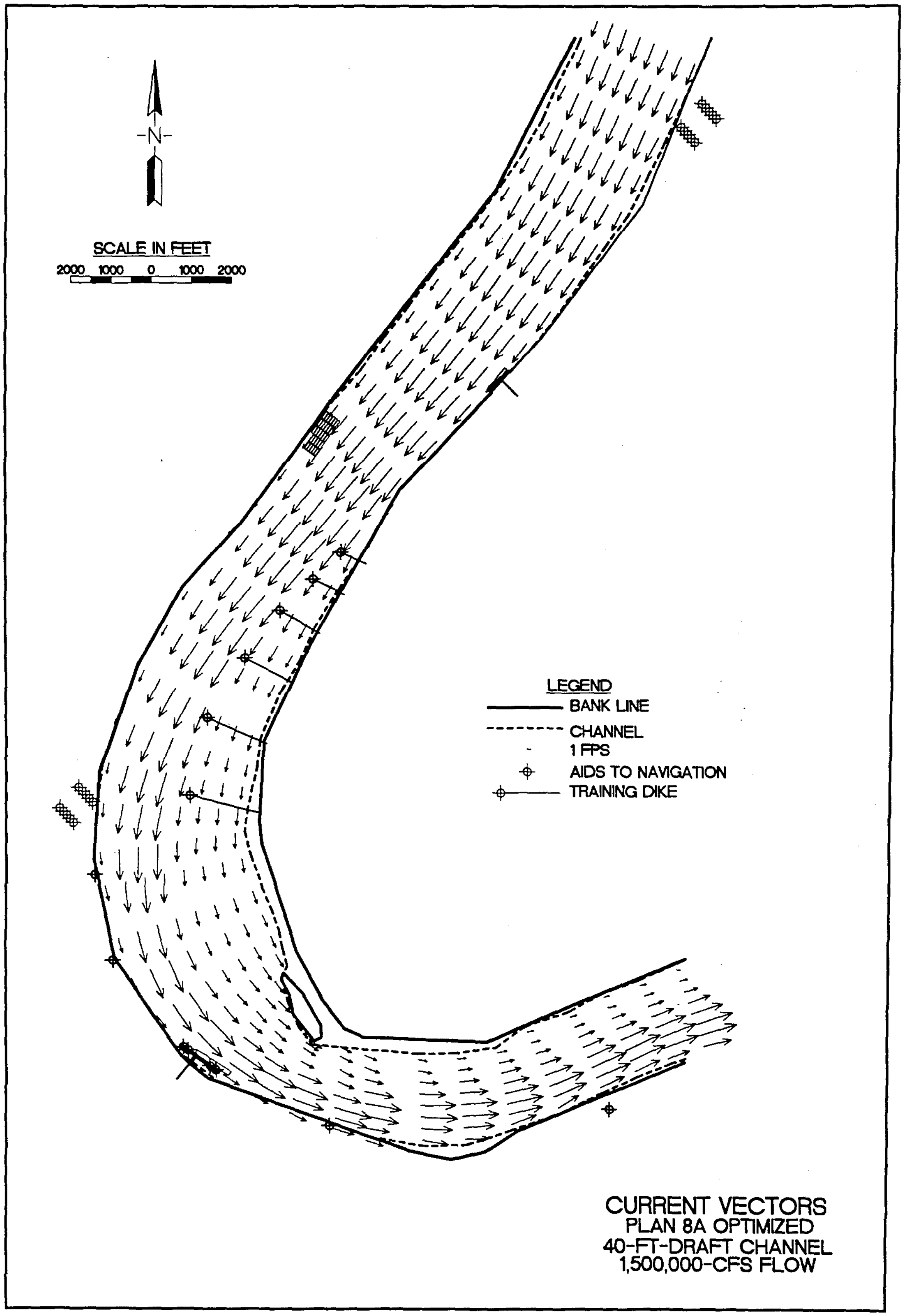
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 8A OPTIMIZED
40-FT-DRAFT CHANNEL
530,000-CFS FLOW



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SCALE IN FEET
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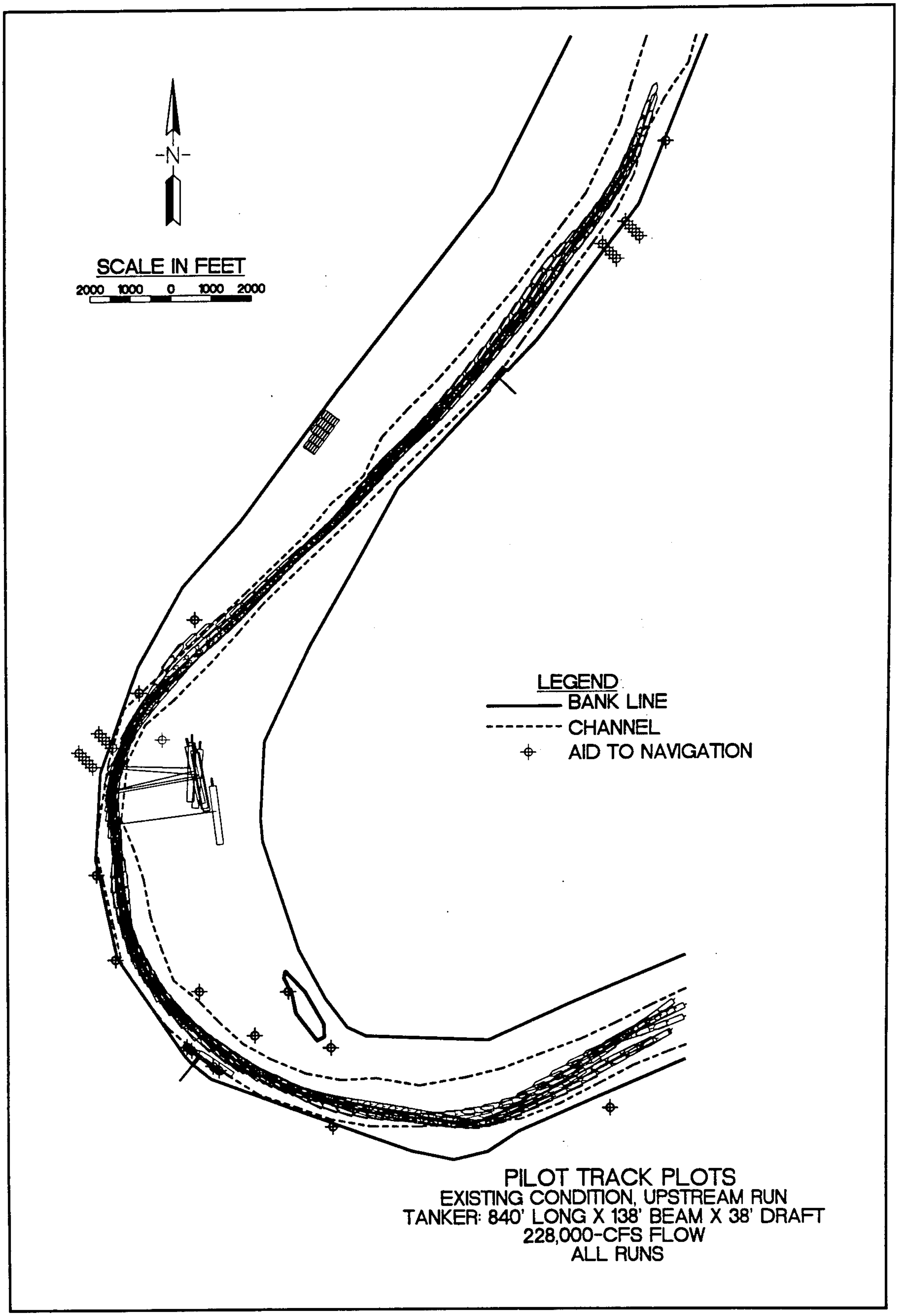
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 8A OPTIMIZED
40-FT-DRAFT CHANNEL
1,500,000-CFS FLOW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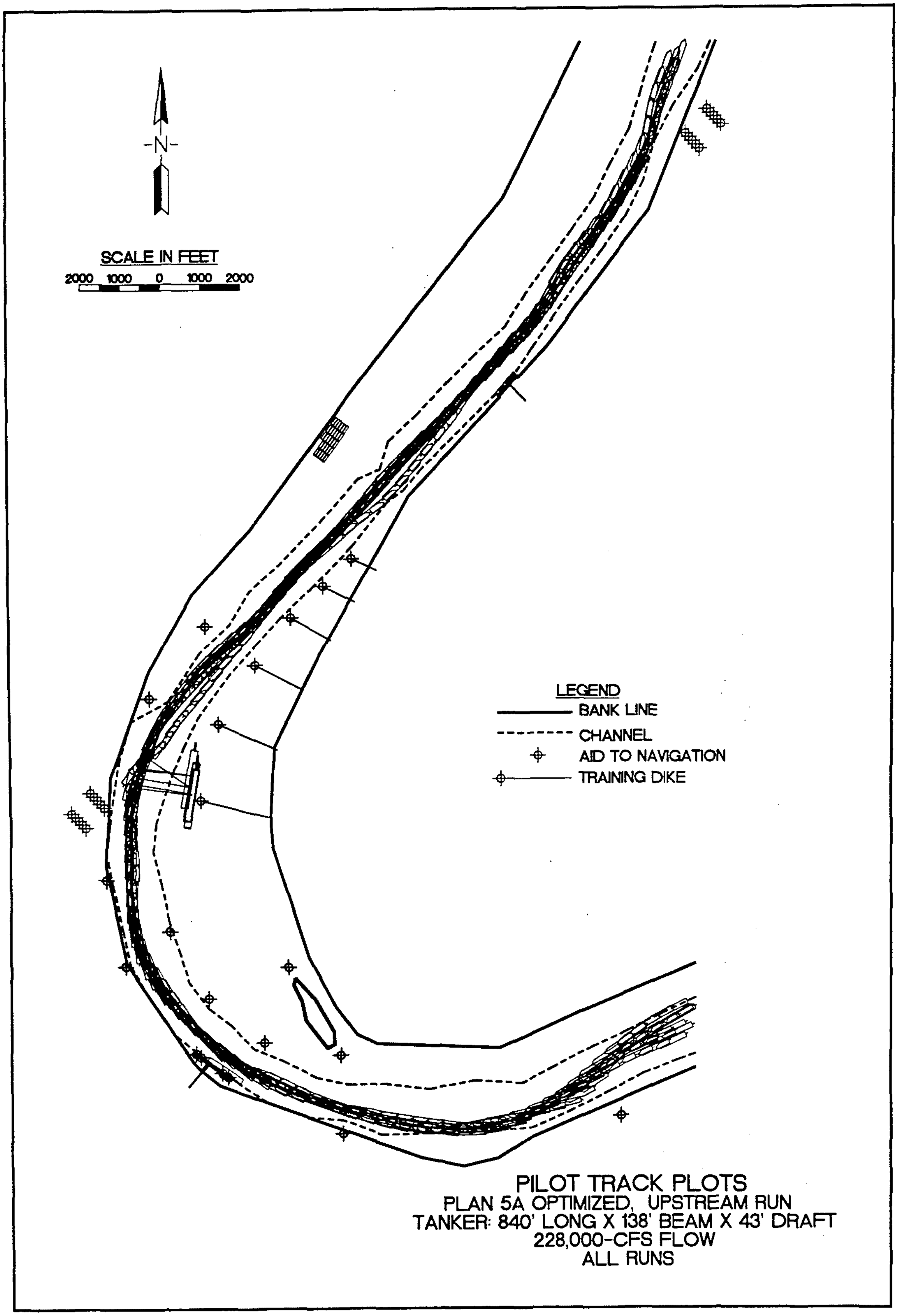
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 38' DRAFT
228,000-CFS FLOW
ALL RUNS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SCALE IN FEET
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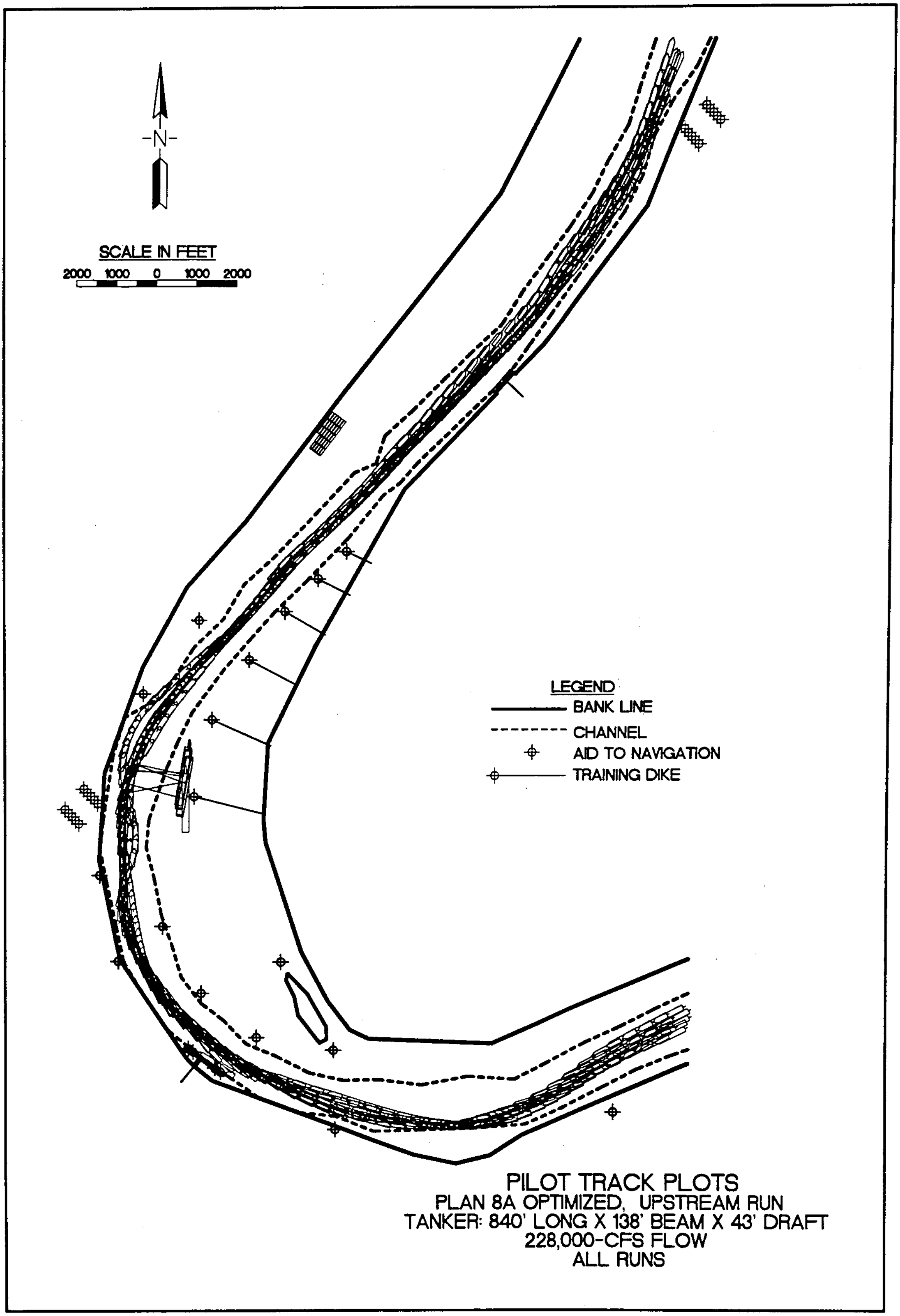
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
228,000-CFS FLOW
ALL RUNS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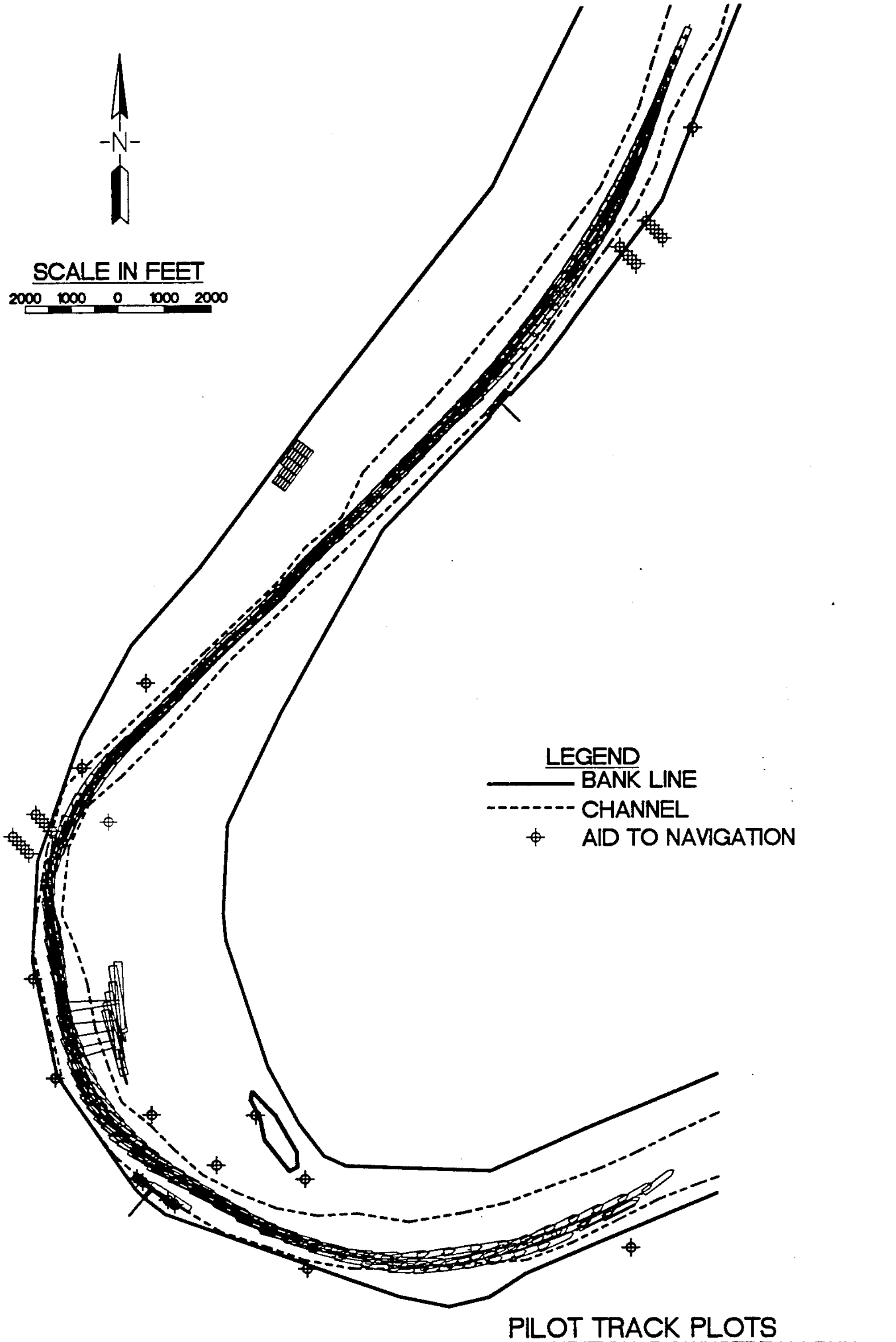
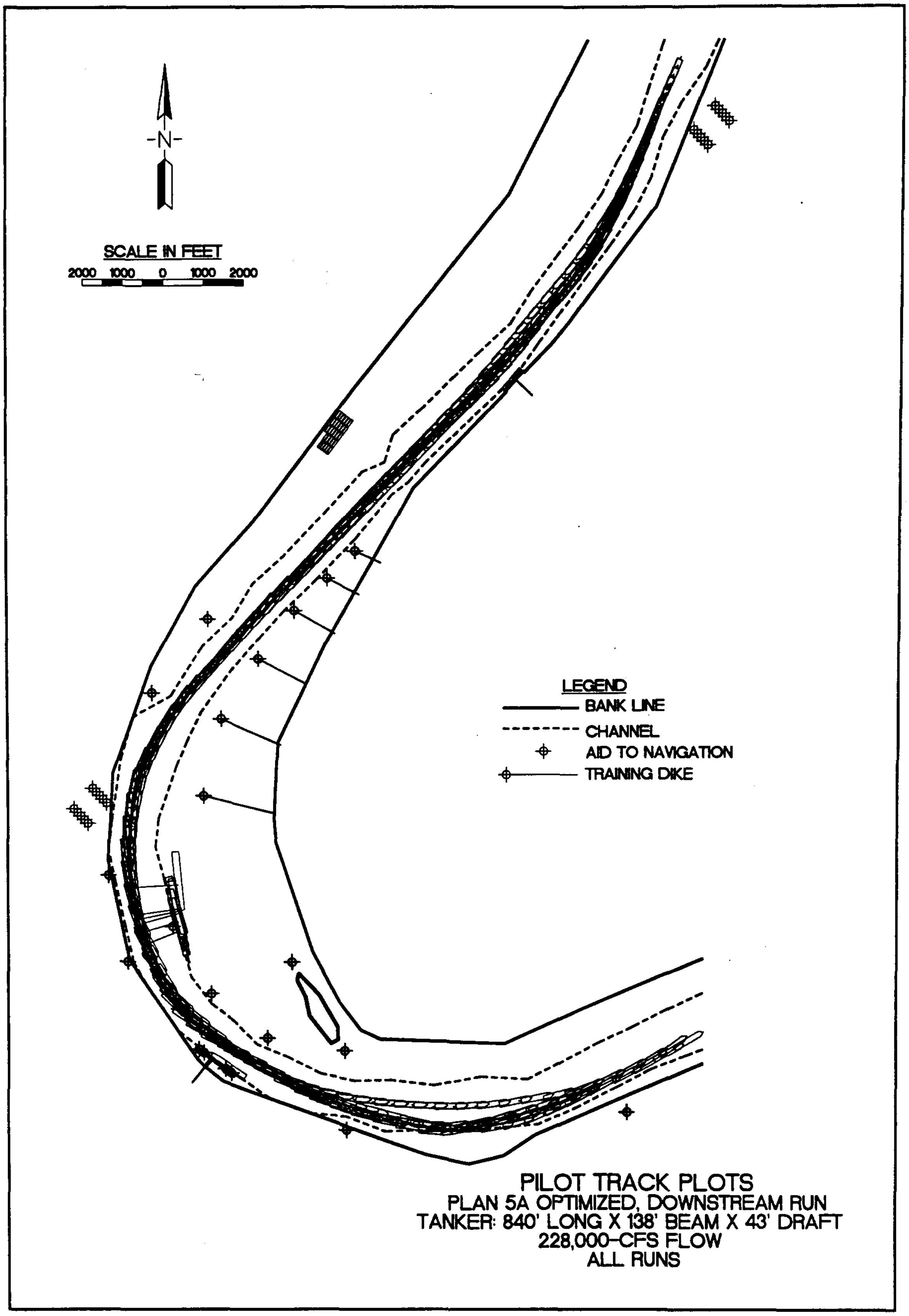
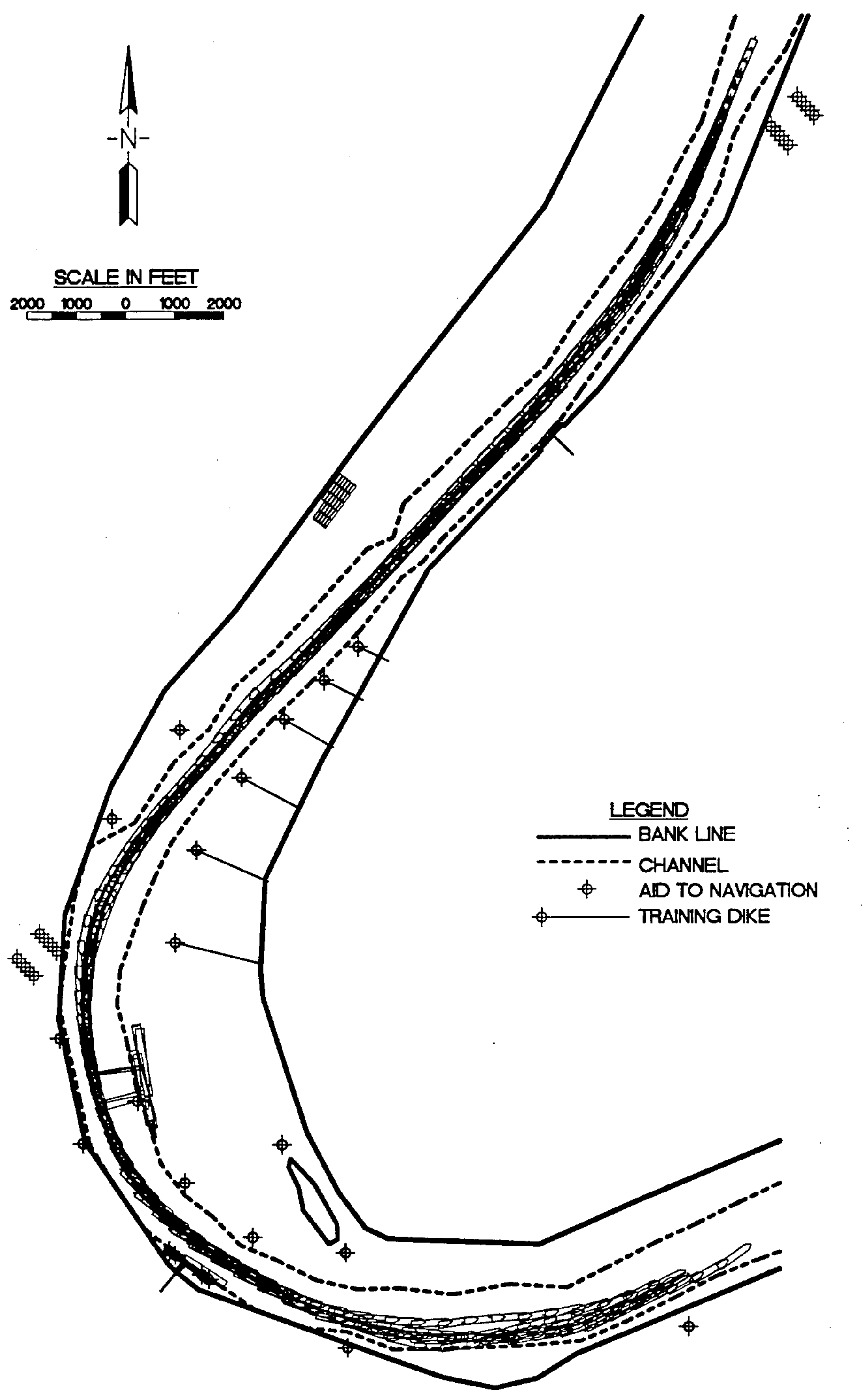
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
228,000-CFS FLOW
ALL RUNS

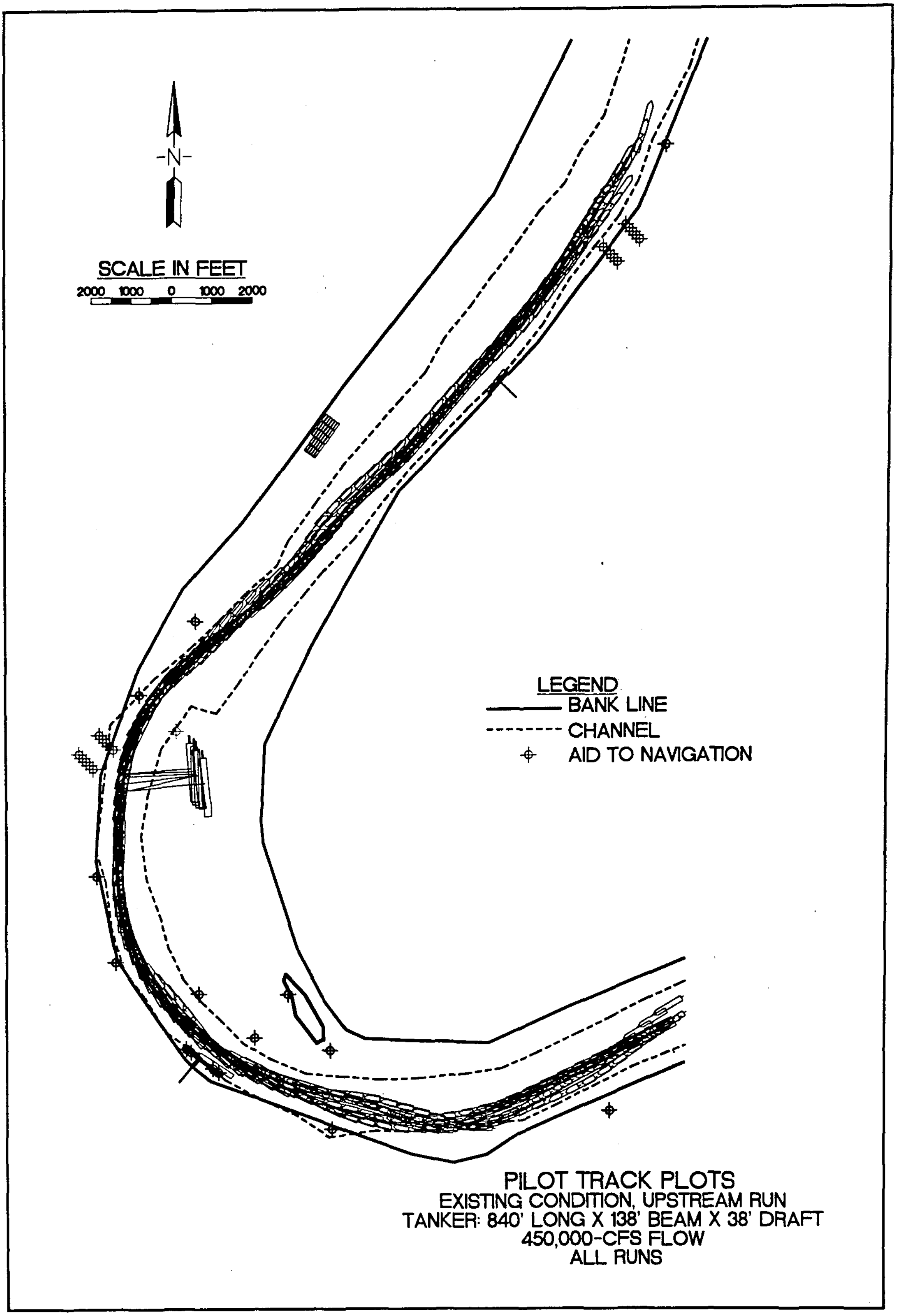


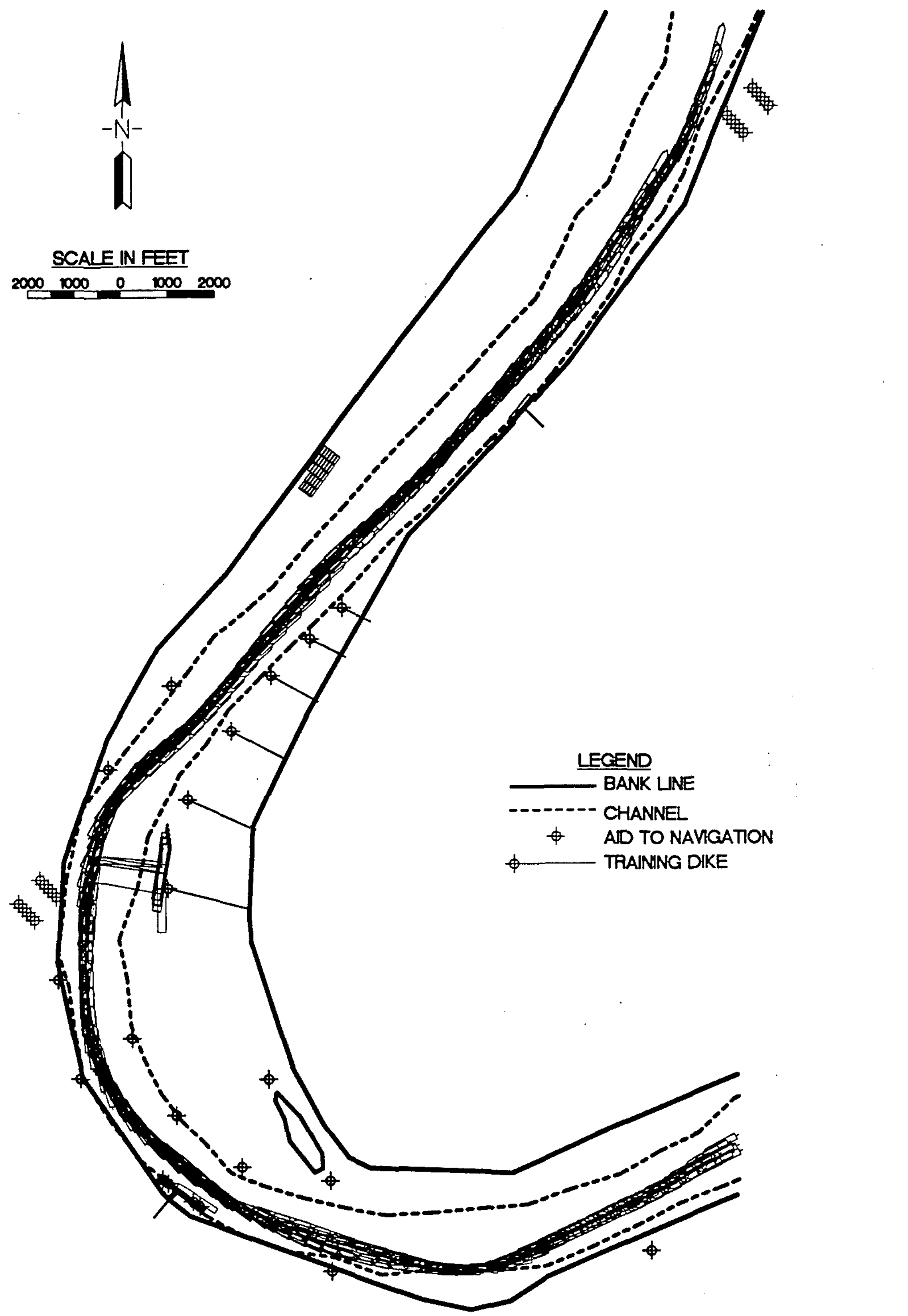

PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 38' DRAFT
228,000-CFS FLOW
ALL RUNS


-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
228,000-CFS FLOW
ALL RUNS

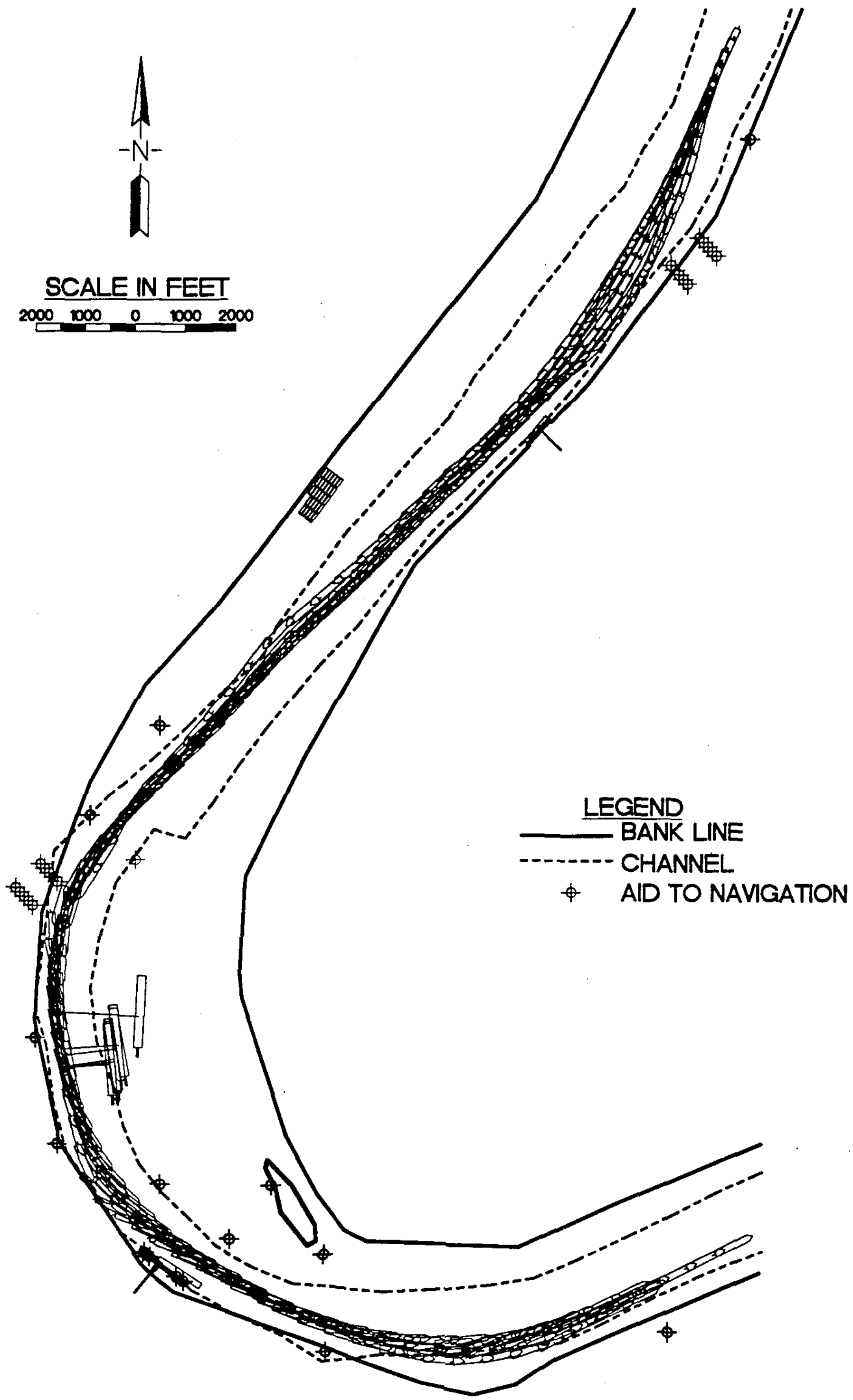



PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
228,000-CFS FLOW
ALL RUNS

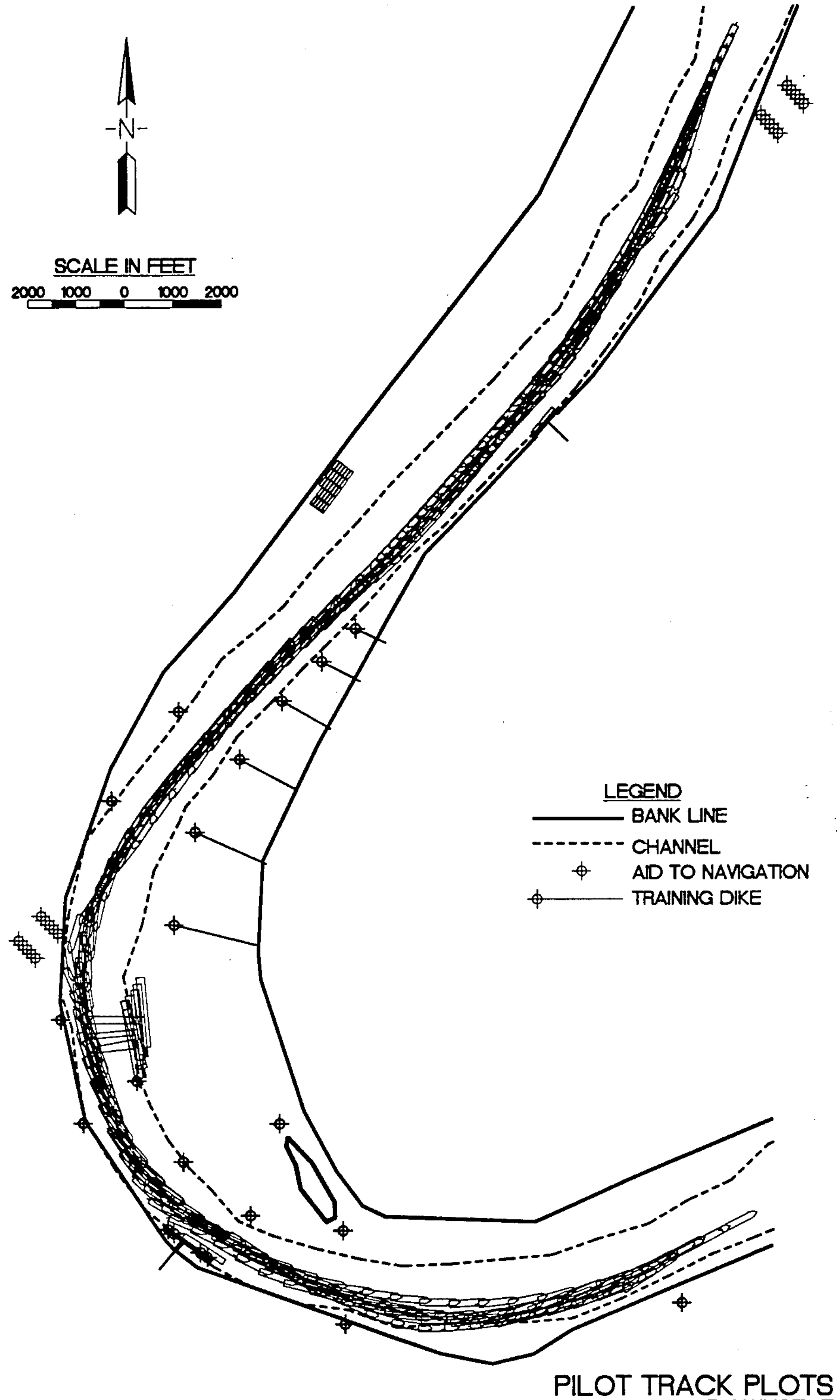

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 38' DRAFT
450,000-CFS FLOW
ALL RUNS



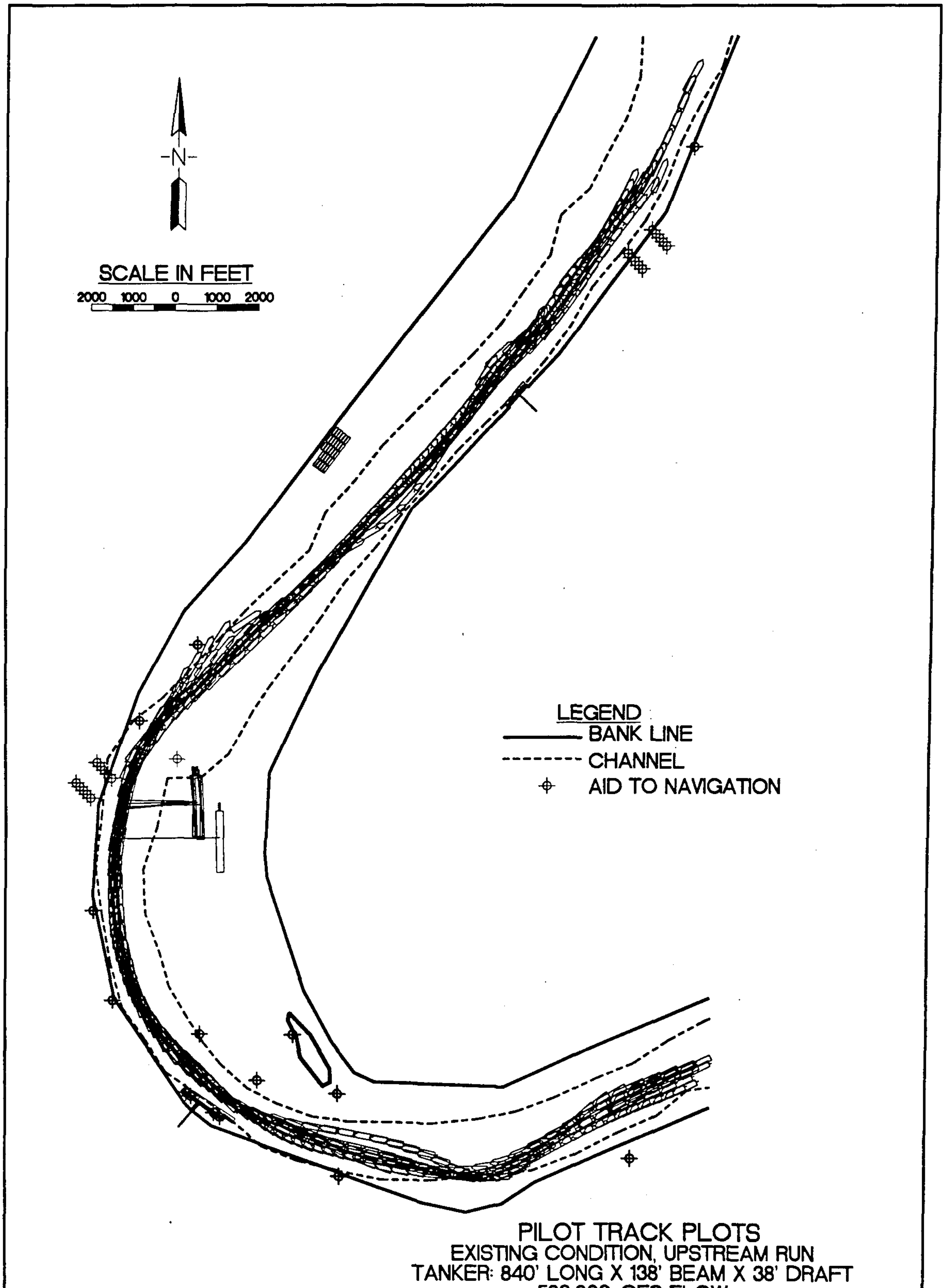

PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
450,000-CFS FLOW
ALL RUNS



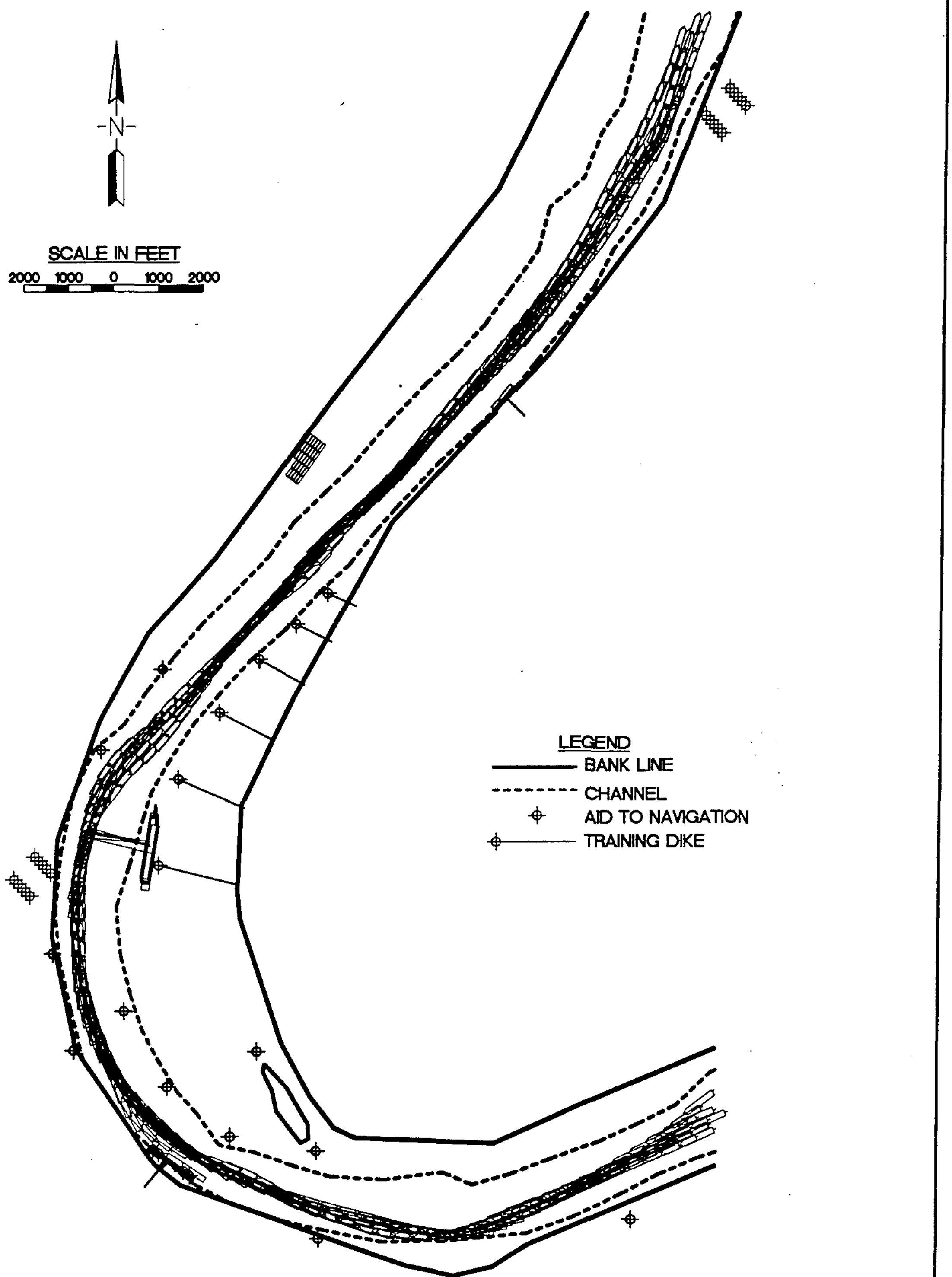

PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 38' DRAFT
450,000-CFS FLOW
ALL RUNS



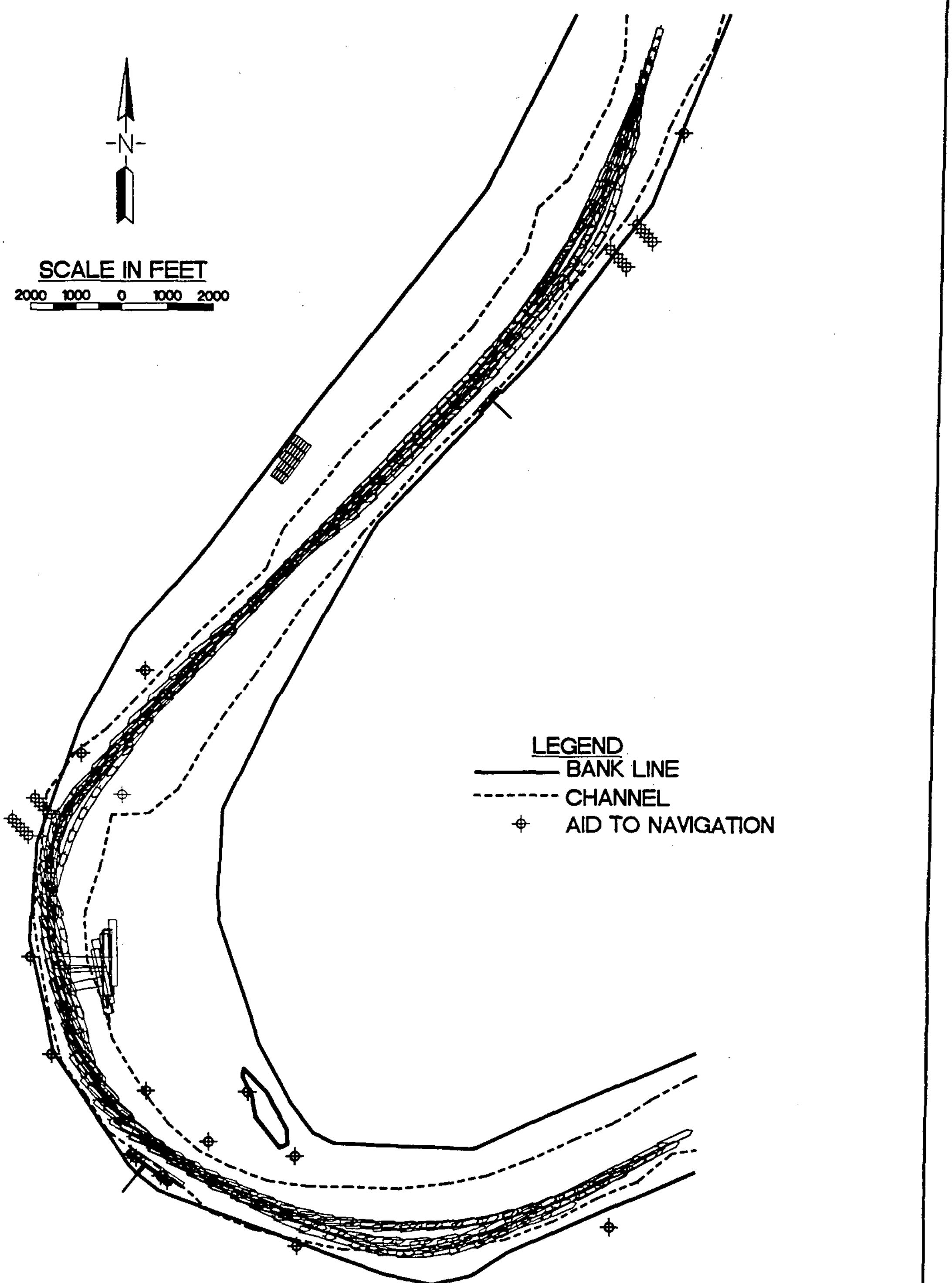

PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
450,000-CFS FLOW
ALL RUNS



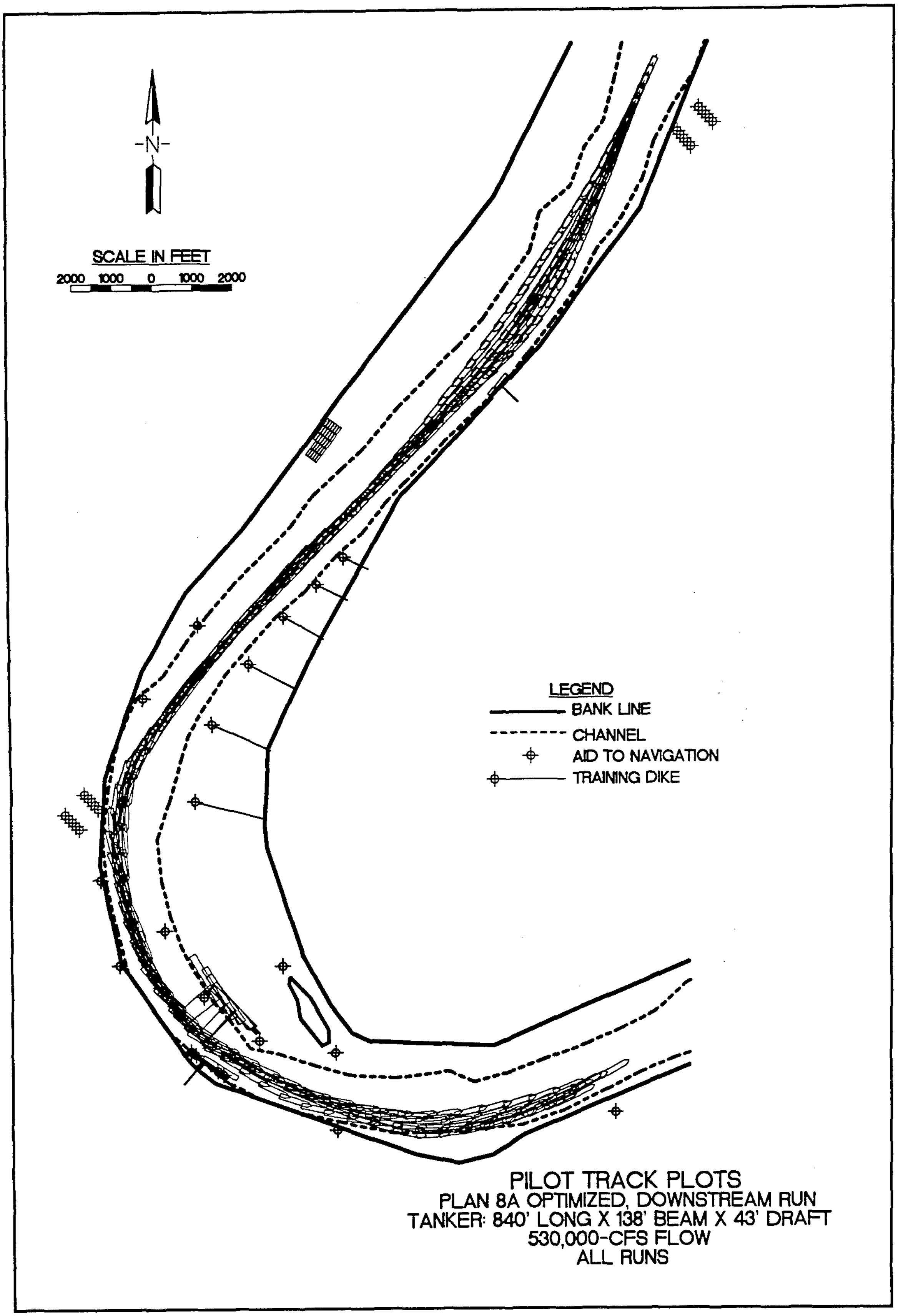

PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 38' DRAFT
530,000-CFS FLOW
ALL RUNS

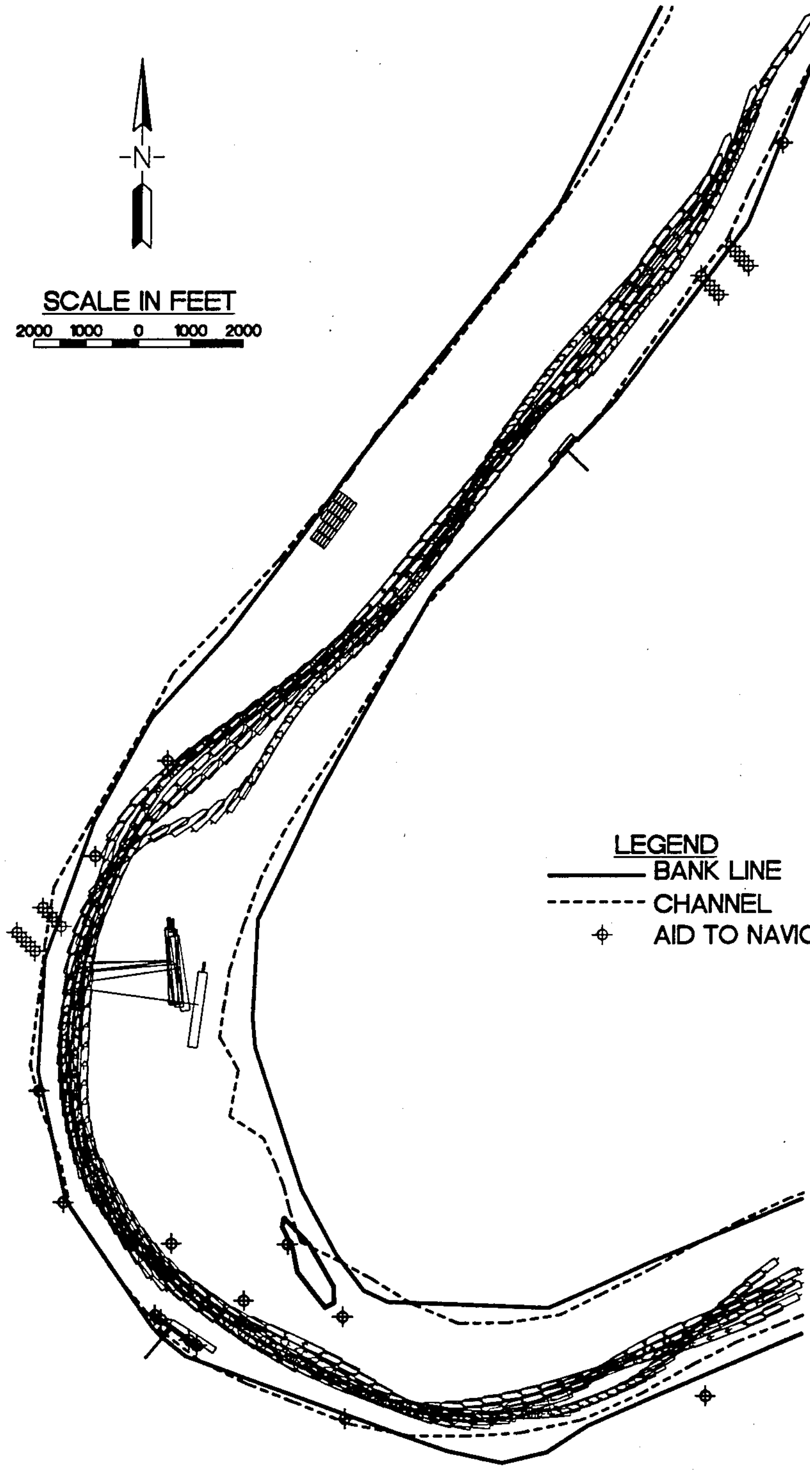



PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
530,000-CFS FLOW
ALL RUNS

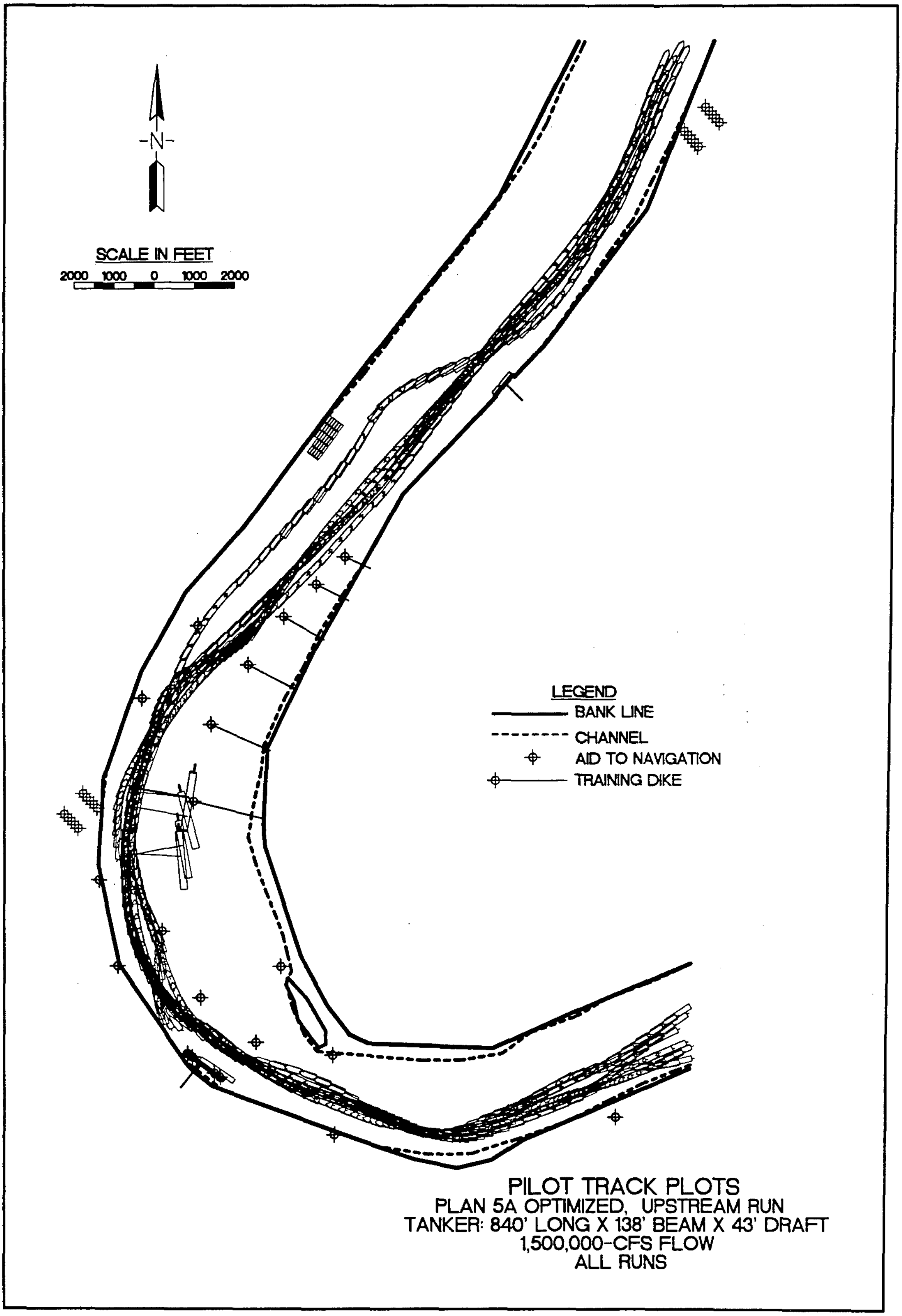


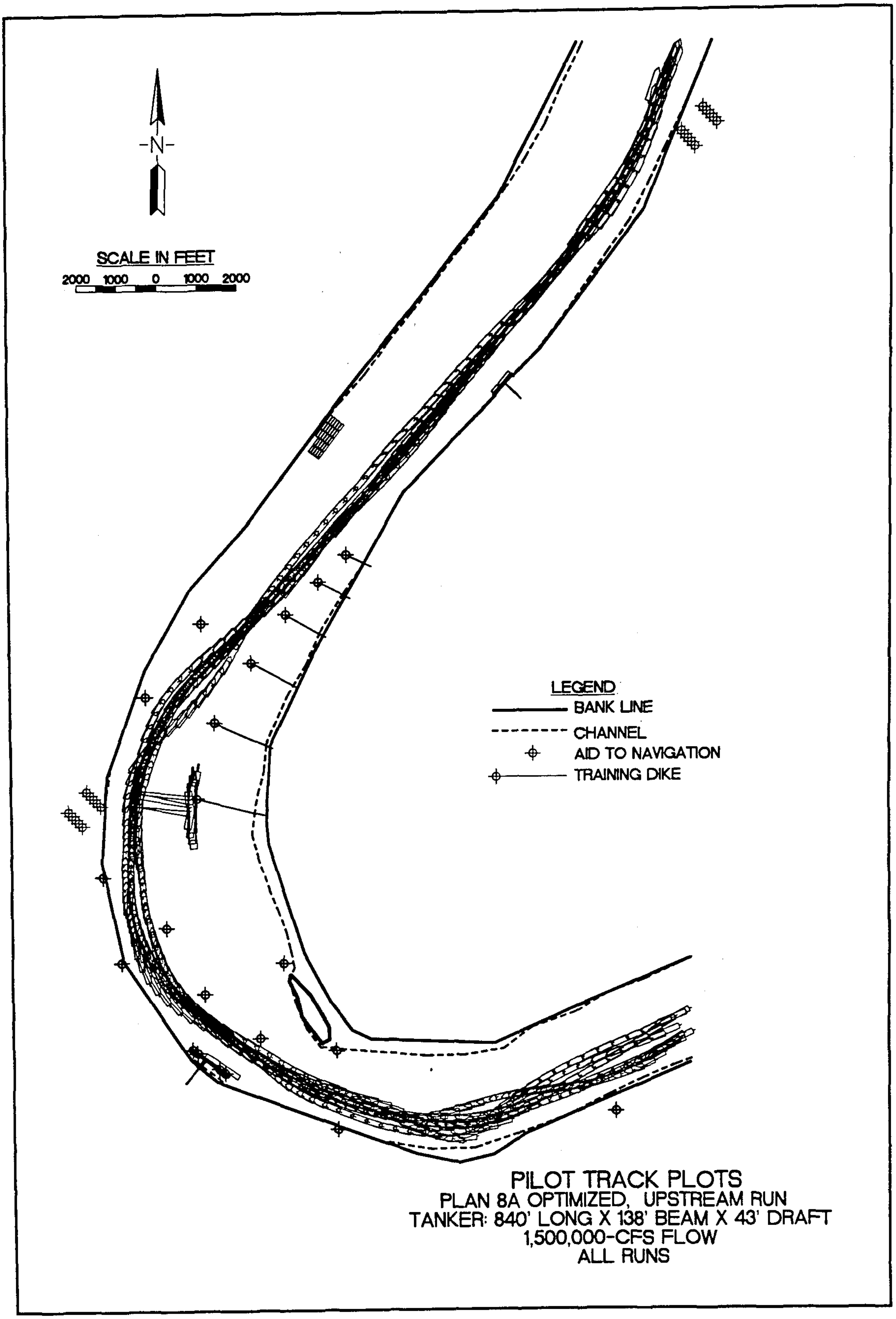

PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 38' DRAFT
530,000-CFS FLOW
ALL RUNS

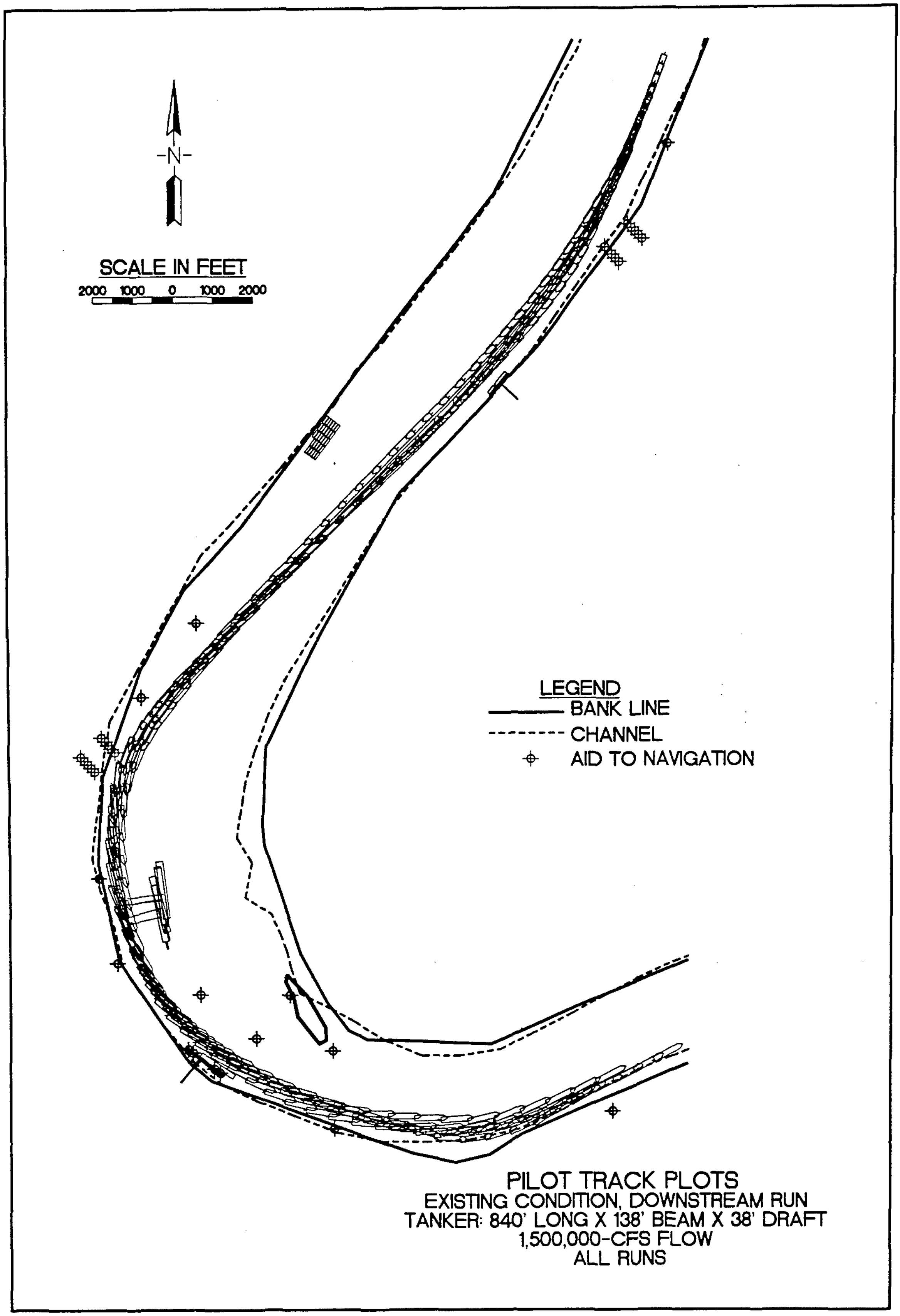

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
530,000-CFS FLOW
ALL RUNS

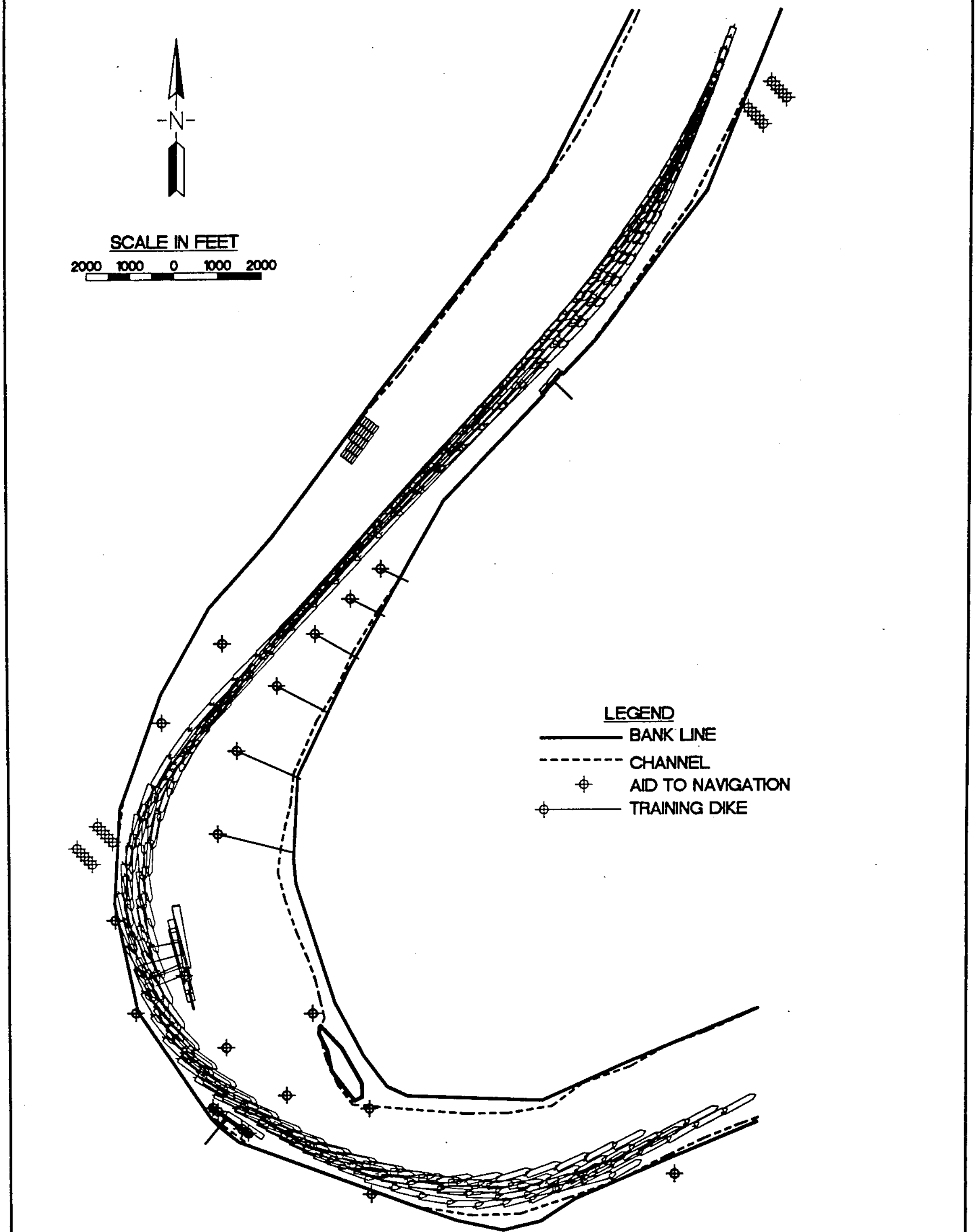



PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 38' DRAFT
1,500,000-CFS FLOW
ALL RUNS

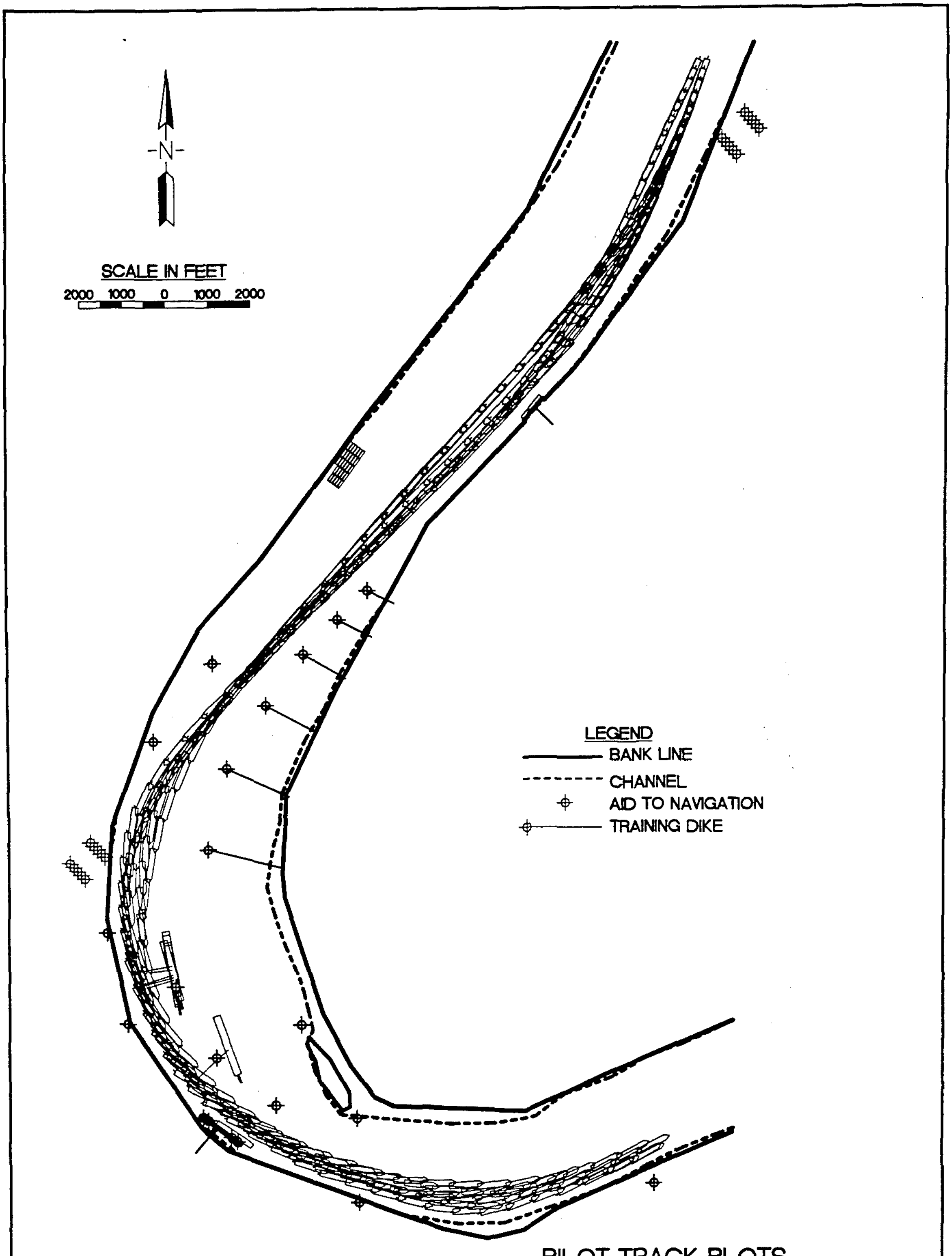

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
1,500,000-CFS FLOW
ALL RUNS


N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, UPSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
1,500,000-CFS FLOW
ALL RUNS

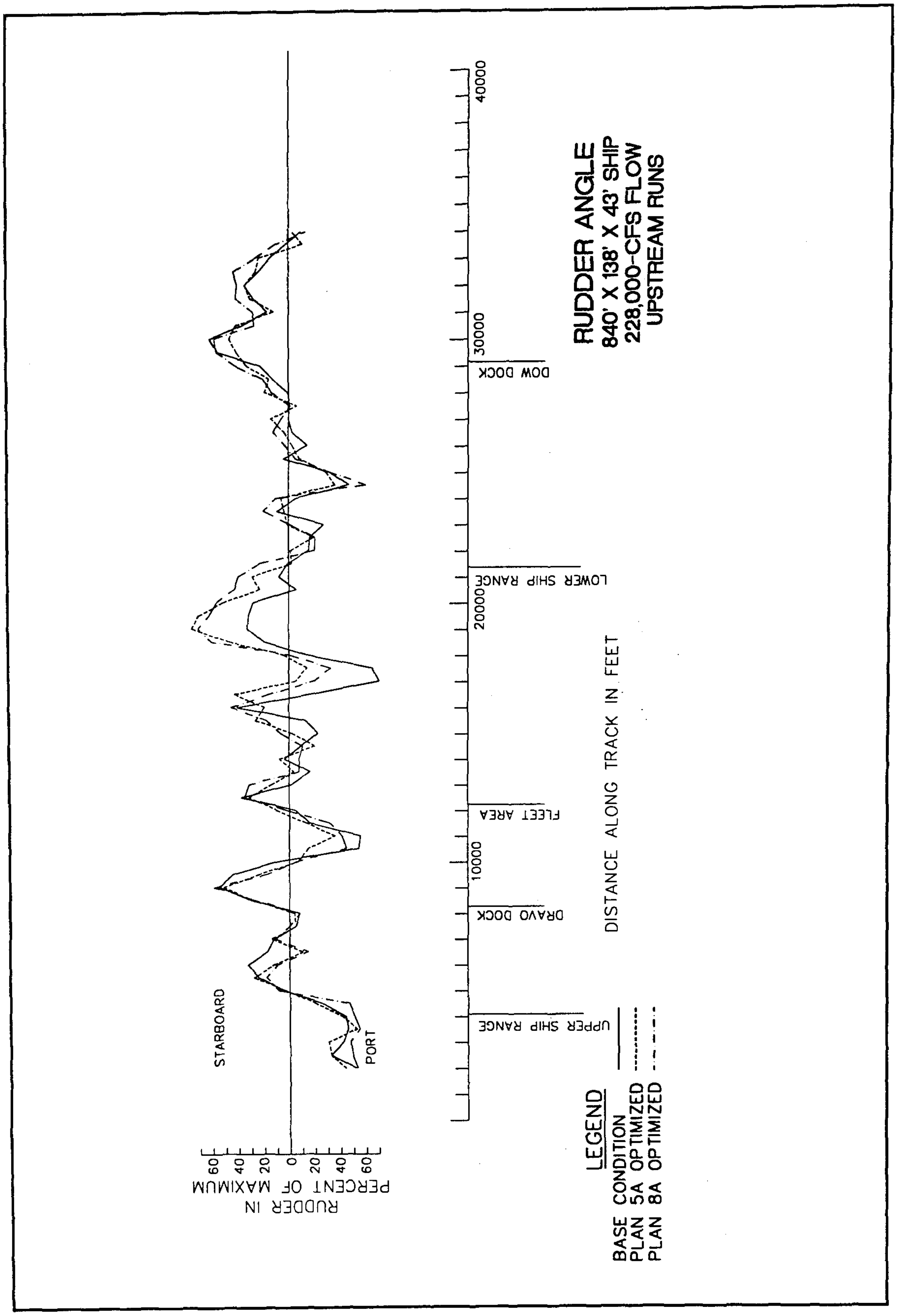

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 38' DRAFT
1,500,000-CFS FLOW
ALL RUNS




PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
1,500,000-CFS FLOW
ALL RUNS




PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, DOWNSTREAM RUN
TANKER: 840' LONG X 138' BEAM X 43' DRAFT
1,500,000-CFS FLOW
ALL RUNS



RUDDER ANGLE
840' X 138' X 43' SHIP
228,000-CFS FLOW
UPSTREAM RUNS
RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
LOWER SHIP RANGE
20000
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED
PLAN 8A OPTIMIZED

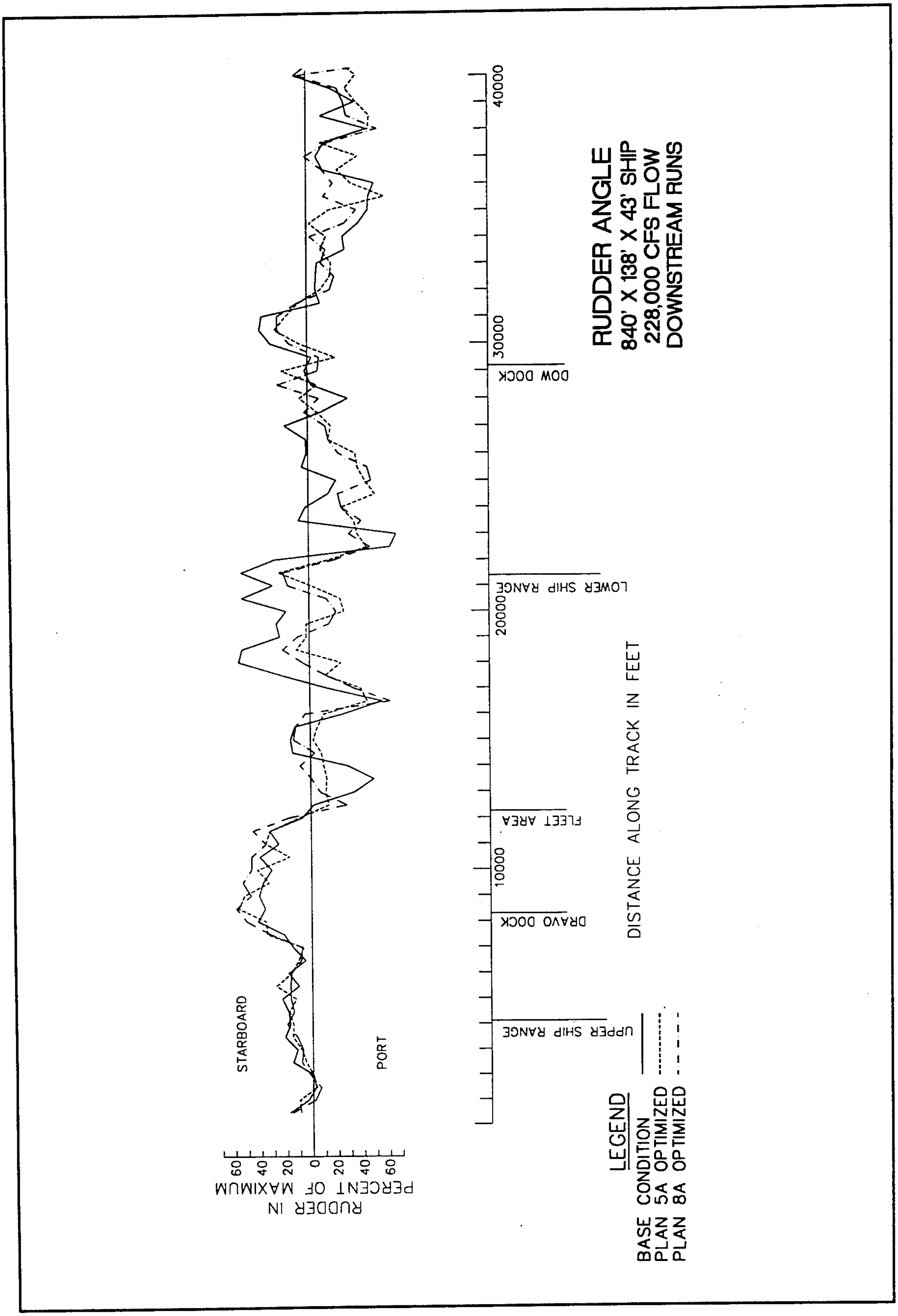
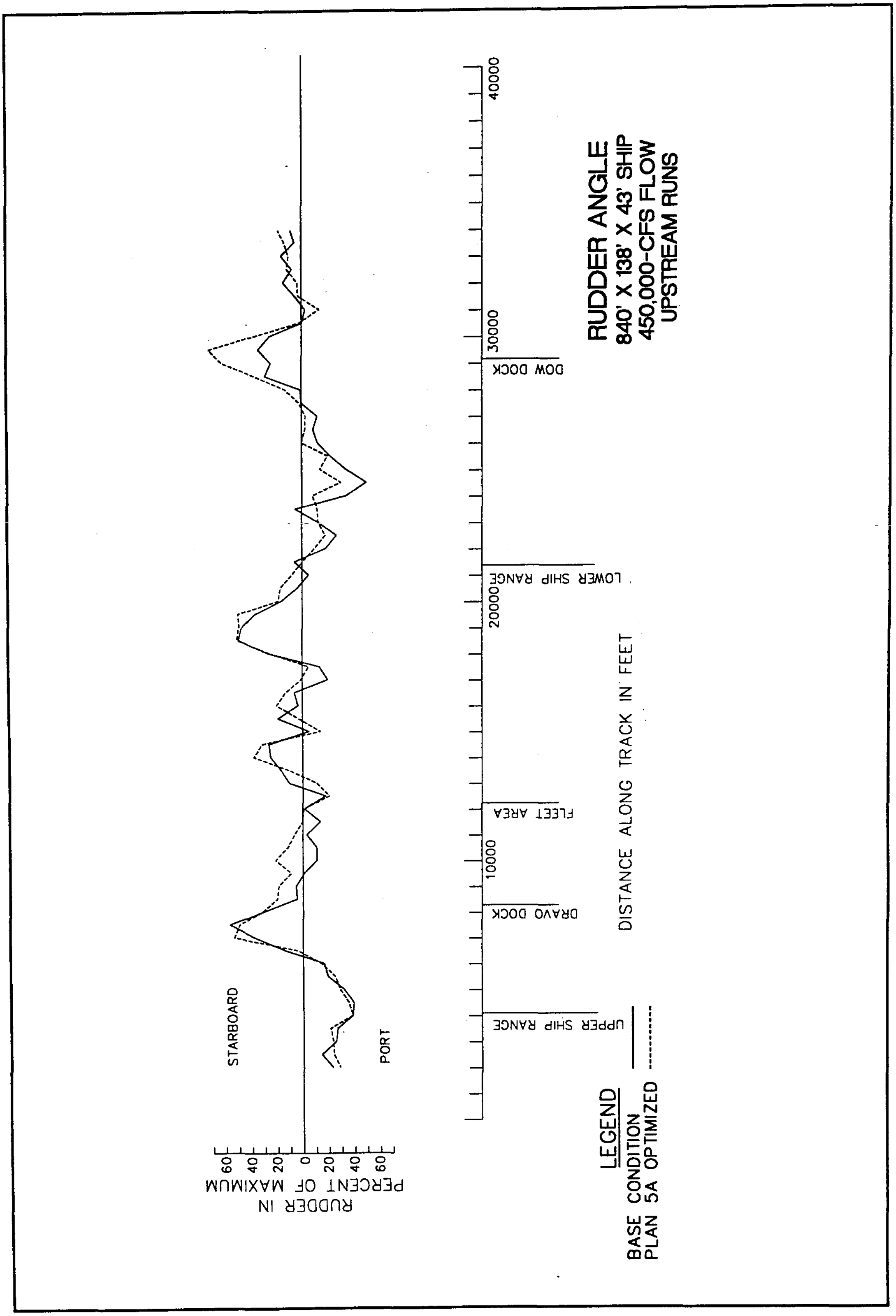
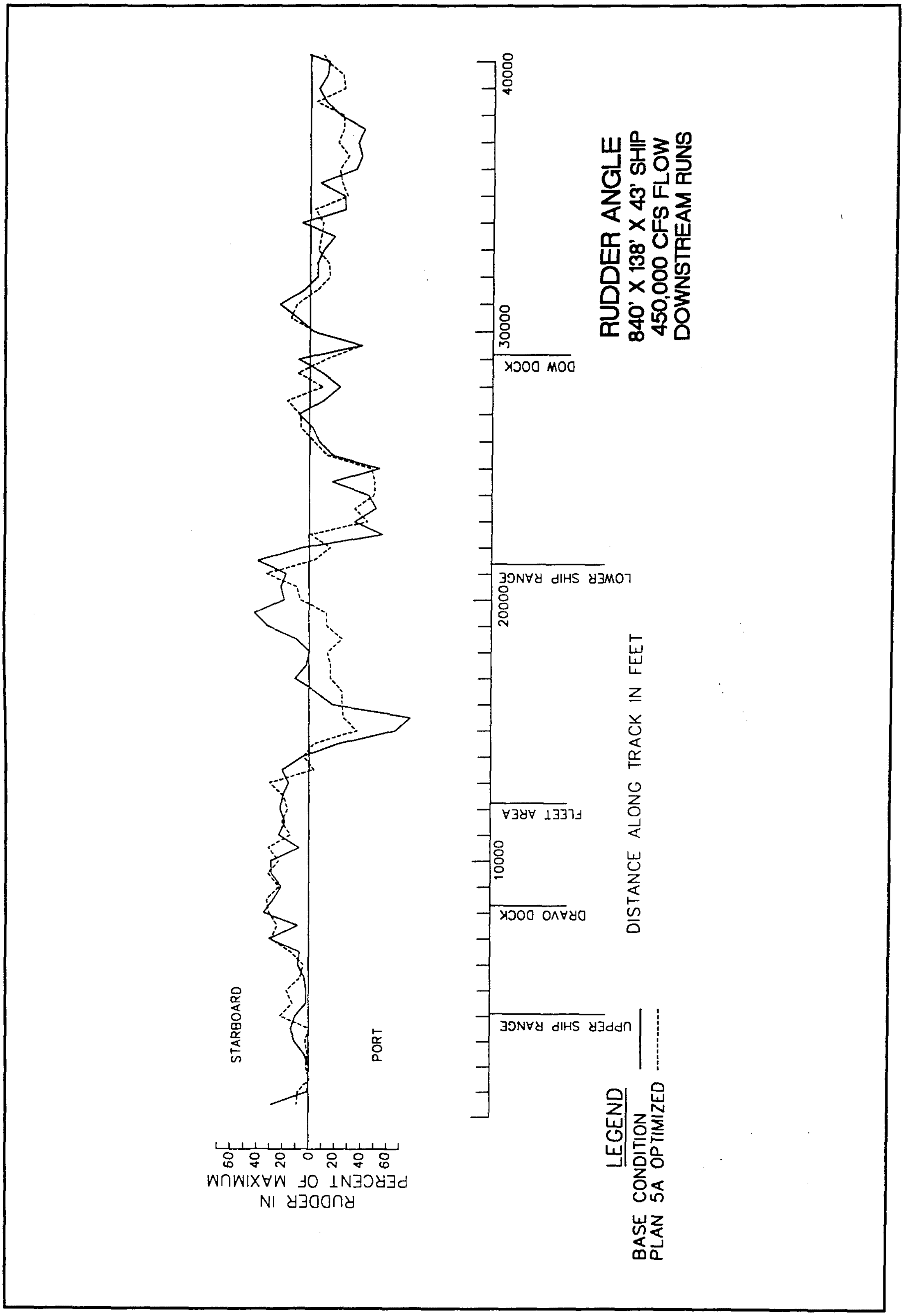
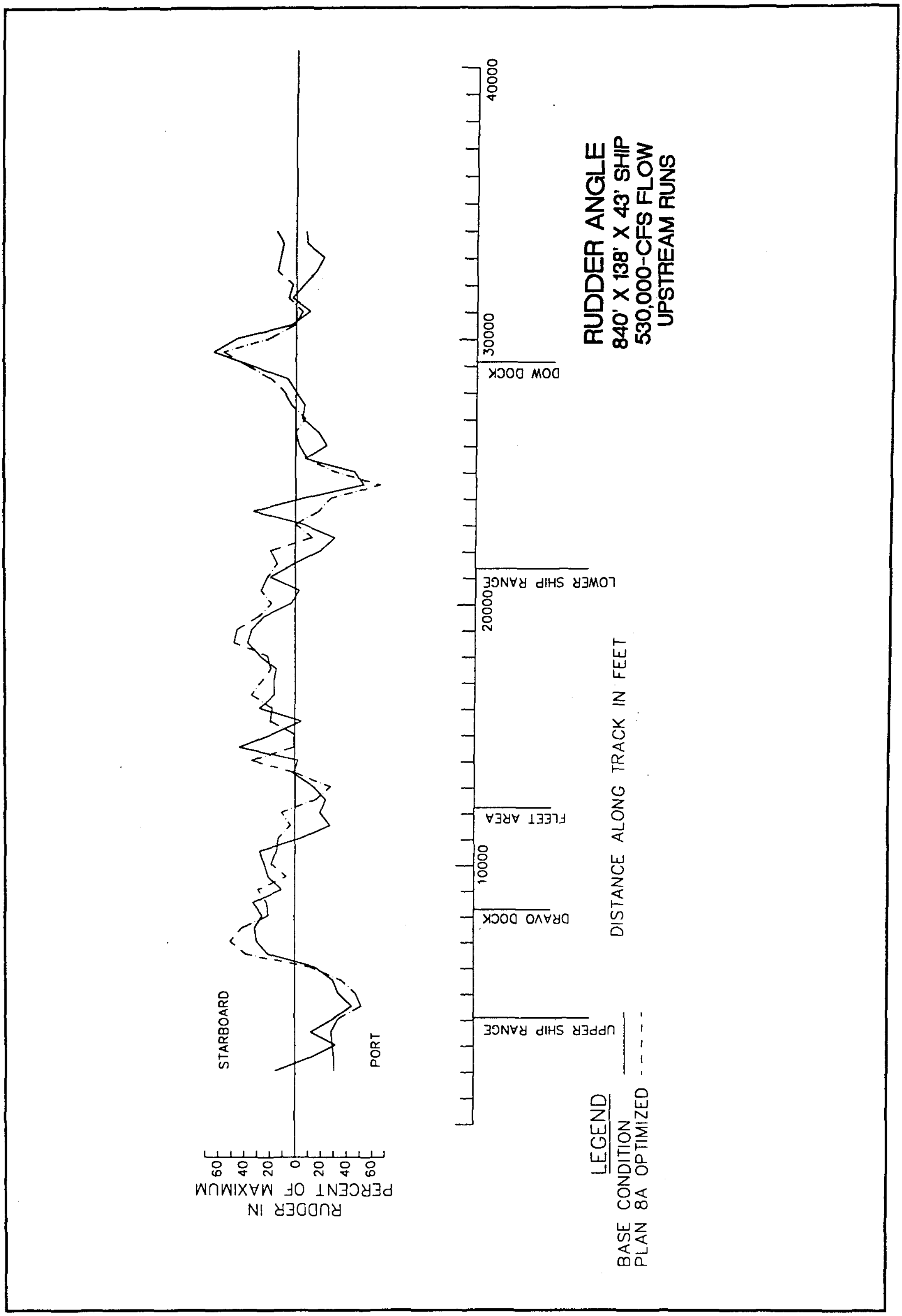
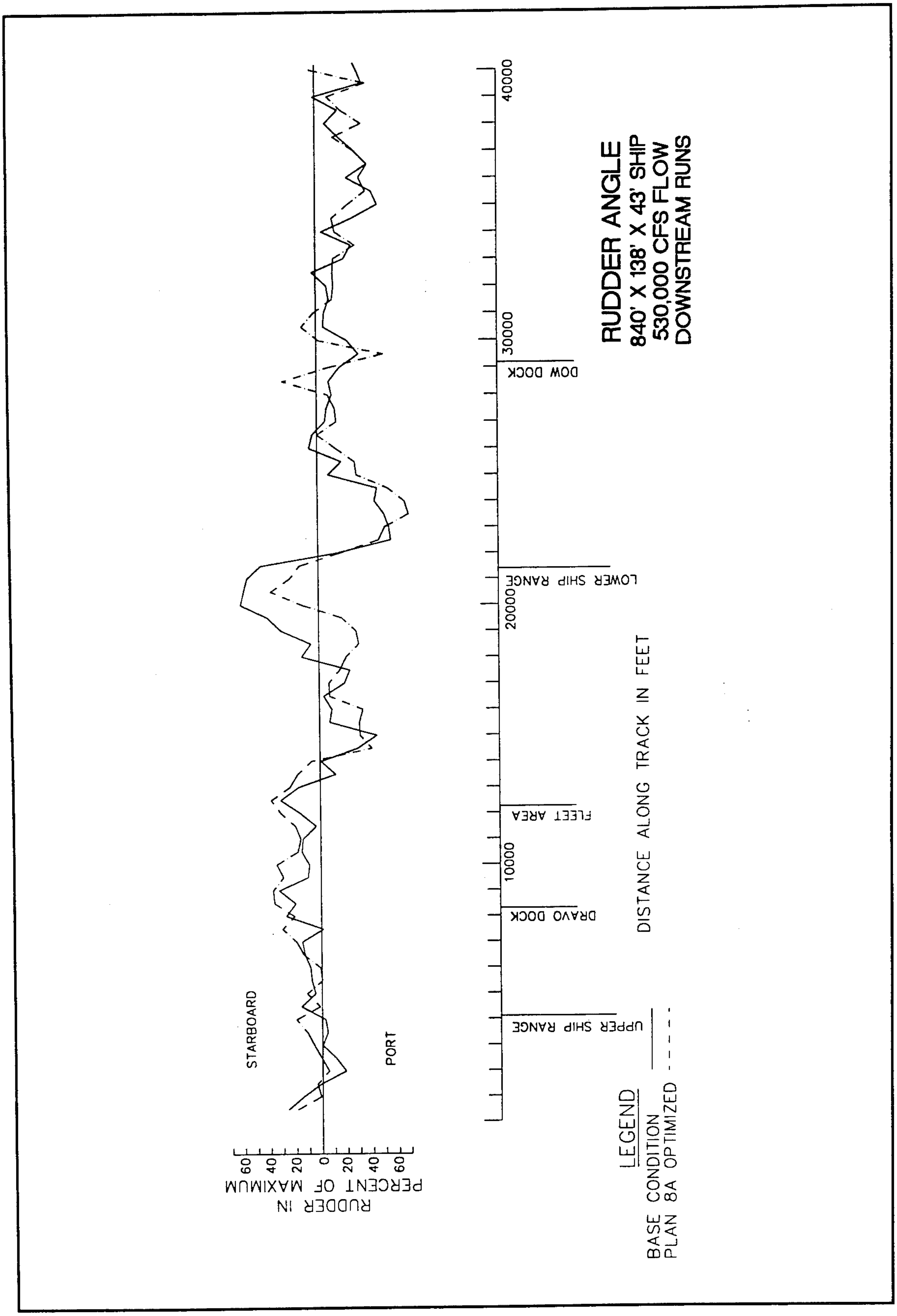

RUDDER ANGLE
840' X 138' X 43' SHIP
228,000 CFS FLOW
DOWNSTREAM RUNS
RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
10000
20000
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED
PLAN 8A OPTIMIZED

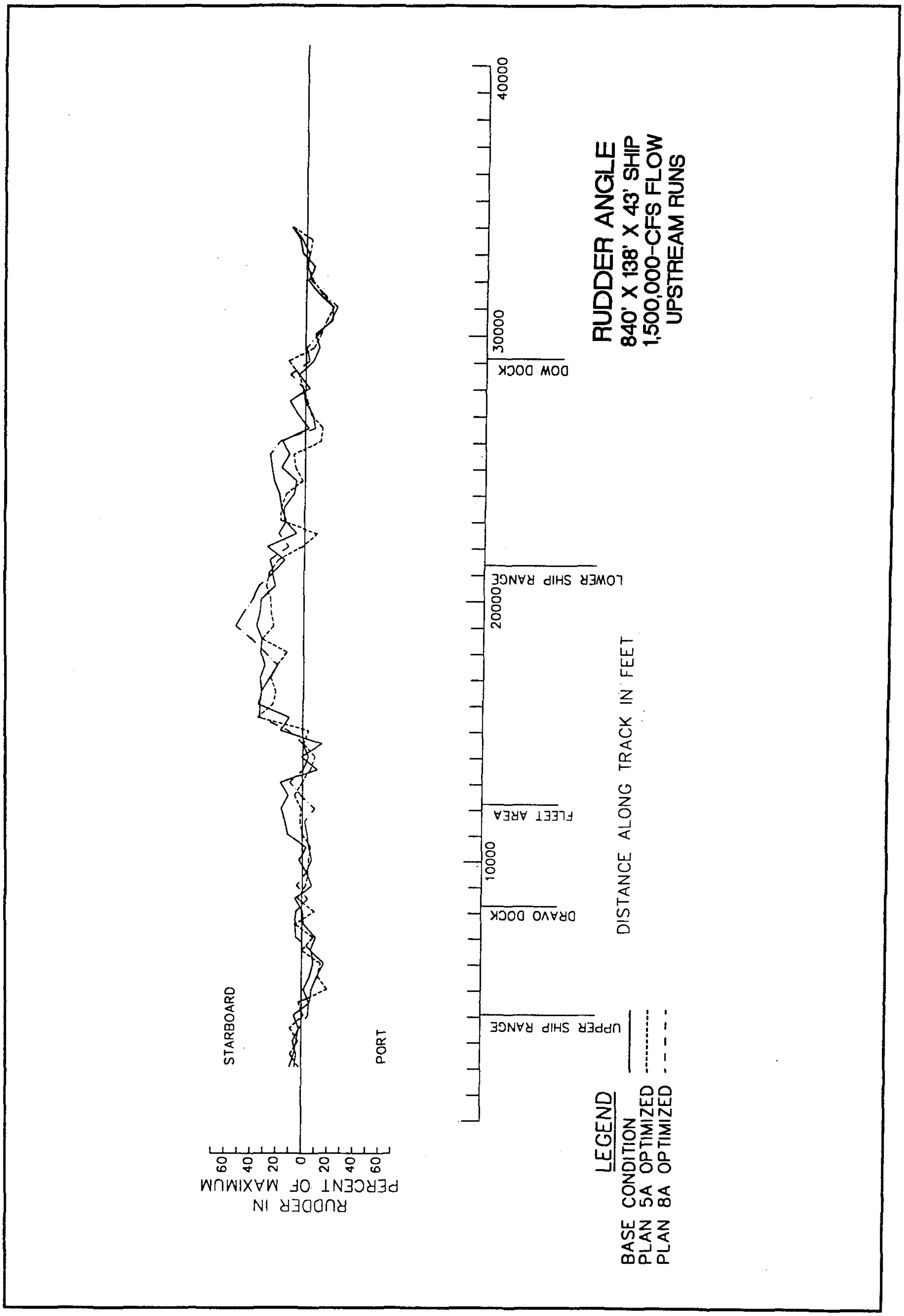
Plate 32

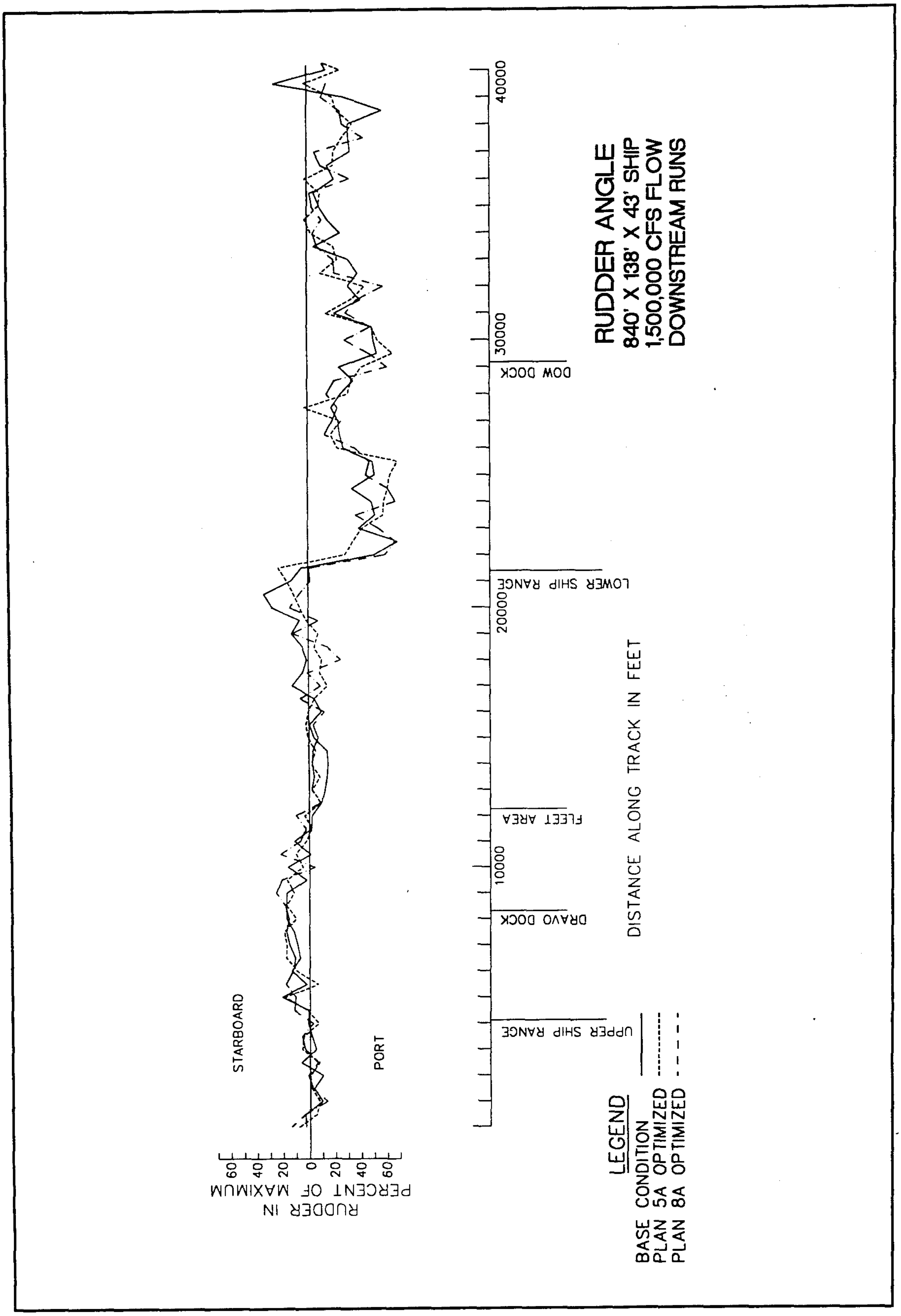

RUDDER ANGLE
840' X 138' X 43' SHIP
450,000-CFS FLOW
UPSTREAM RUNS
RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
10000
20000
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

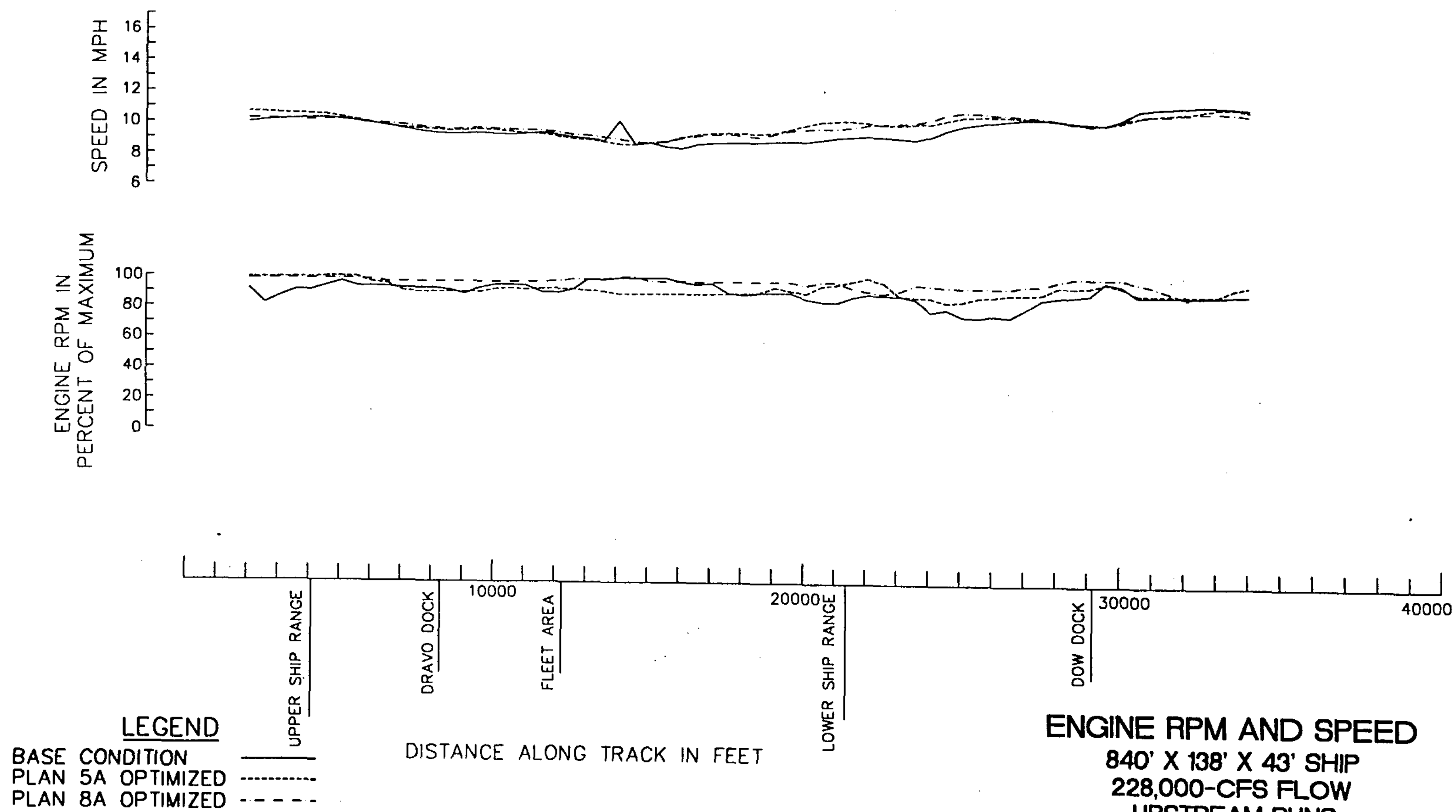

RUDDER ANGLE
840' X 138' X 43' SHIP
450,000 CFS FLOW
DOWNSTREAM RUNS
RUDDER IN
PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED


RUDDER ANGLE
840' X 138' X 43' SHIP
530,000-CFS FLOW
UPSTREAM RUNS
RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
DISTANCE ALONG TRACK IN FEET
10000
20000
30000
40000
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


RUDDER ANGLE
840' X 138' X 43' SHIP
530,000 CFS FLOW
DOWNSTREAM RUNS
RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


RUDDER ANGLE
840' X 138' X 43' SHIP
1,500,000-CFS FLOW
UPSTREAM RUNS
RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED
PLAN 8A OPTIMIZED


RUDDER ANGLE
840' X 138' X 43' SHIP
1,500,000 CFS FLOW
DOWNSTREAM RUNS
RUDDER IN
PERCENT OF MAXIMUM
60
40
20
0
20
40
60
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED
PLAN 8A OPTIMIZED




**ENGINE RPM AND SPEED**
**840' X 138' X 43' SHIP**
**228,000-CFS FLOW**
**UPSTREAM RUNS**

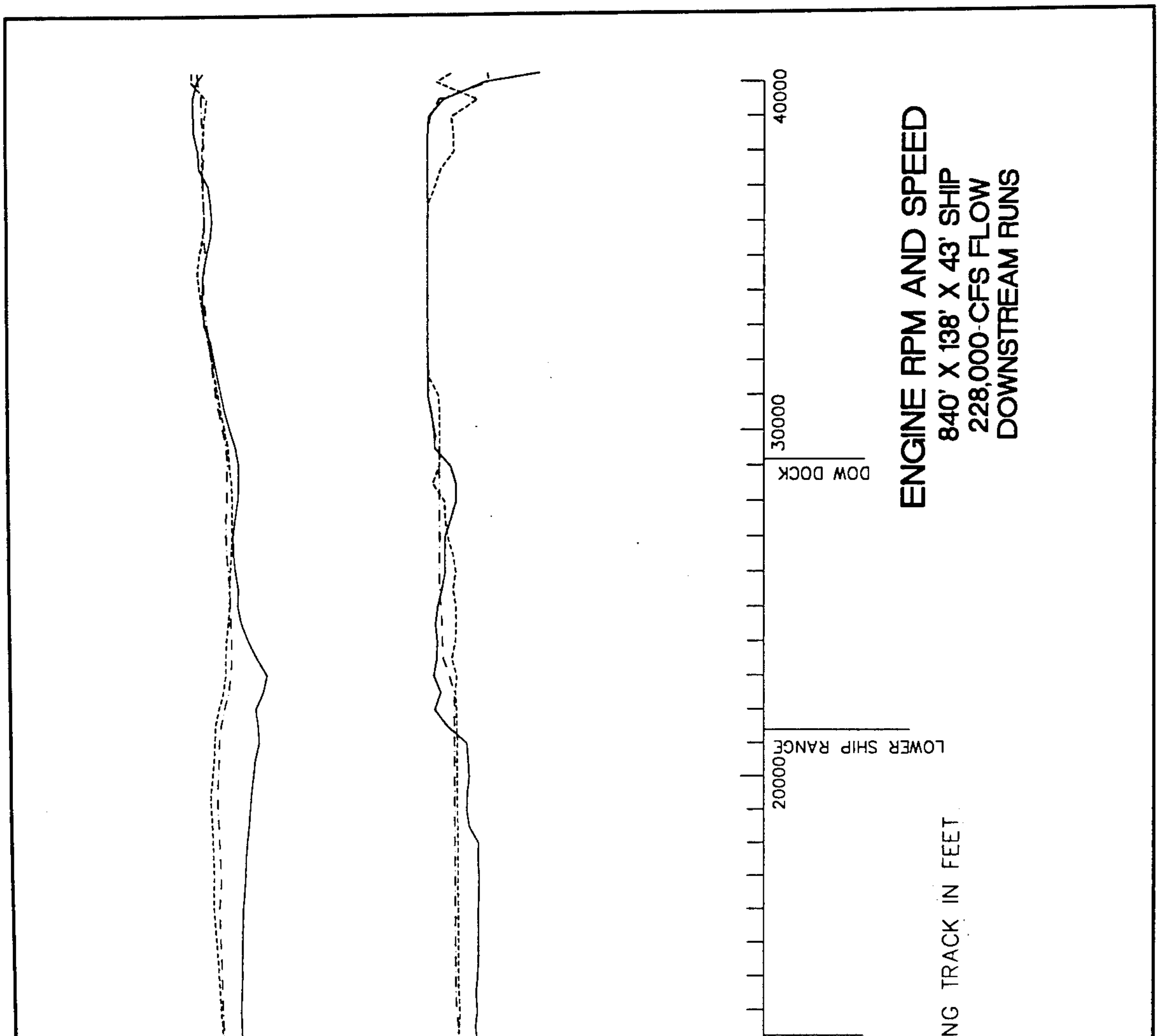
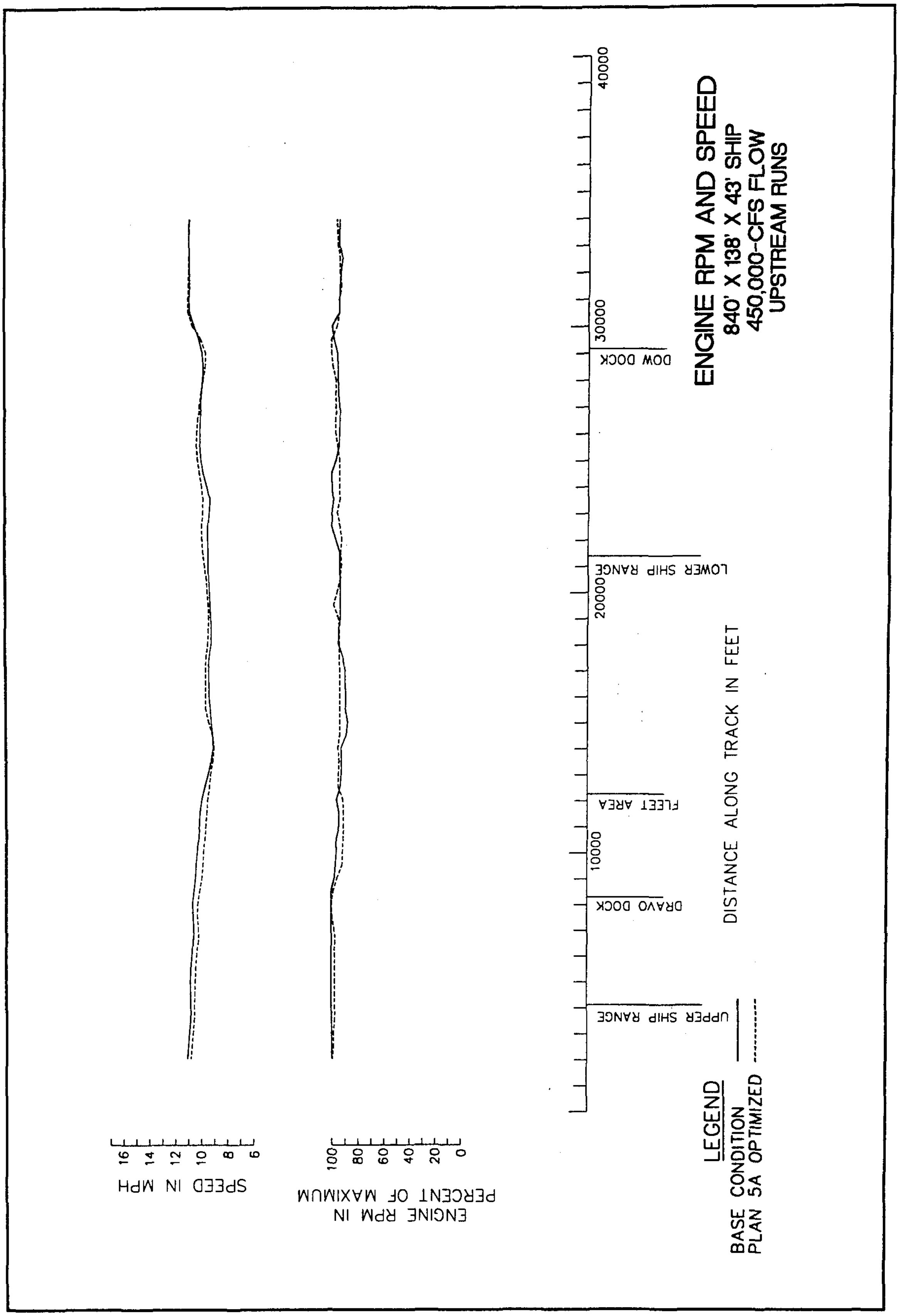

ENGINE RPM AND SPEED
840' X 138' X 43' SHIP
228,000-CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
16
14
12
10
8
6
ENGINE RPM IN PERCENT OF MAXIMUM
100
80
60
40
20
0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED
PLAN 8A OPTIMIZED

Plate 40


ENGINE RPM AND SPEED
840' X 138' X 43' SHIP
450,000-CFS FLOW
UPSTREAM RUNS
SPEED IN MPH
16 14 12 10 8 6
ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

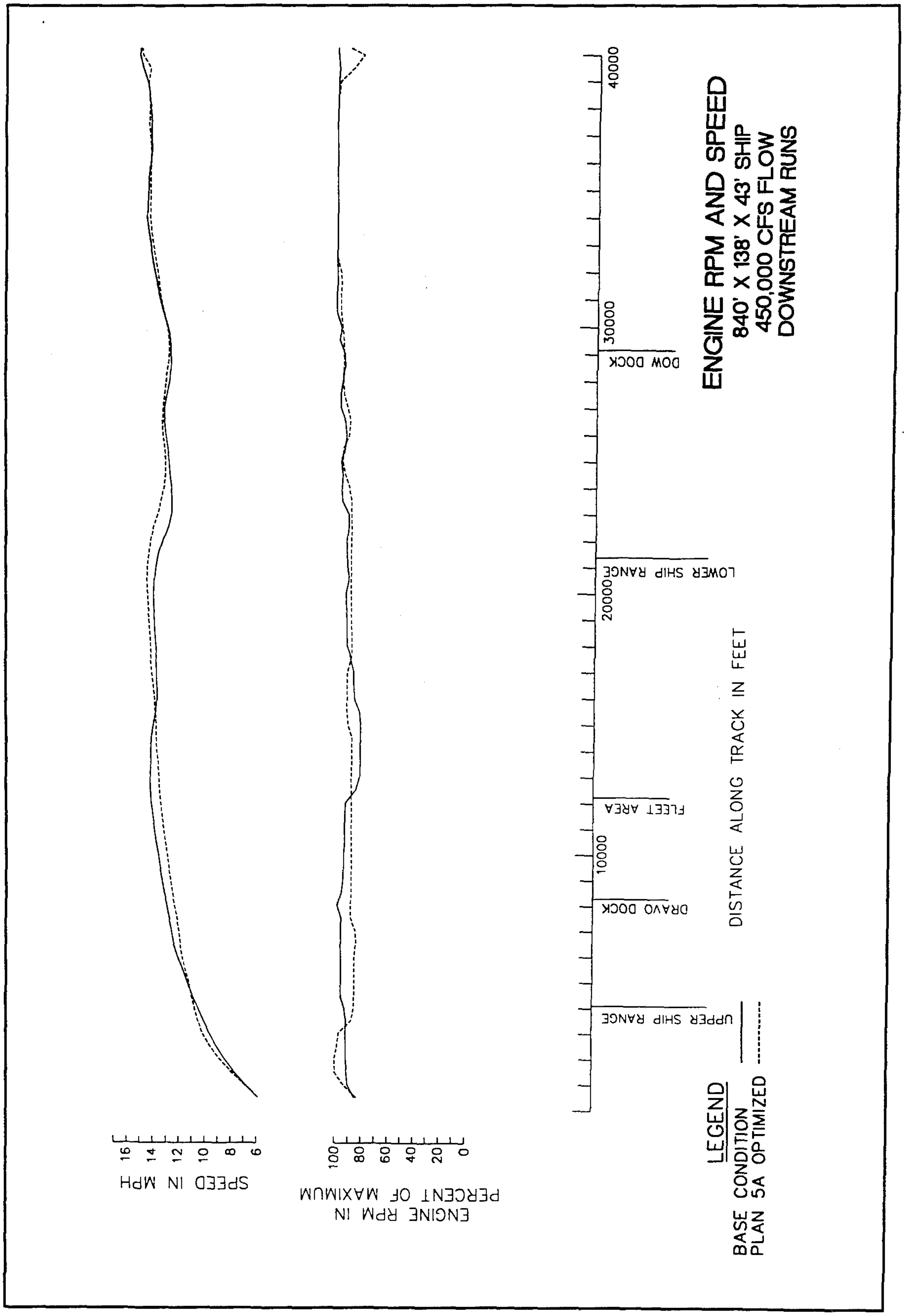
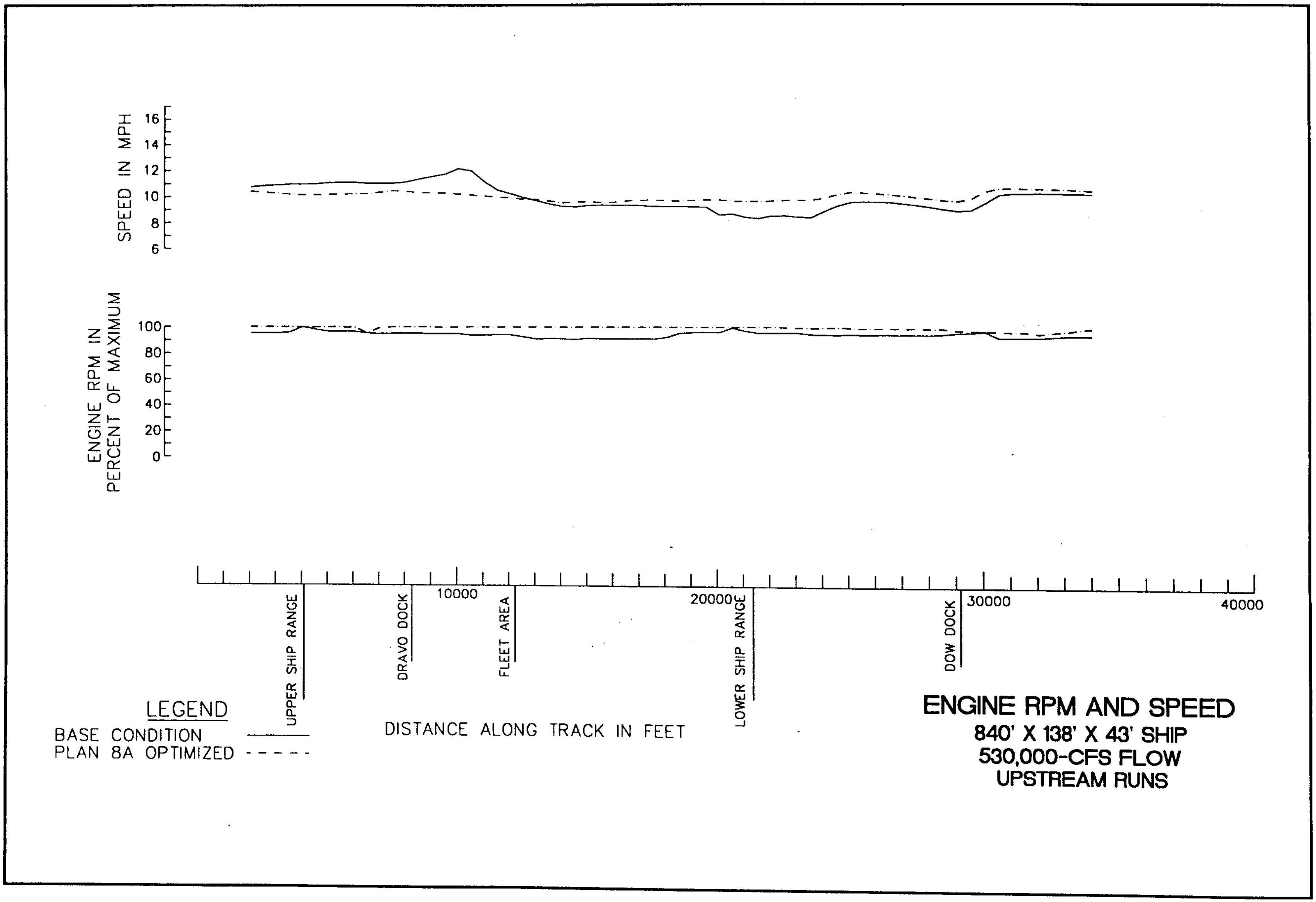

ENGINE RPM AND SPEED
840' X 138' X 43' SHIP
450,000 CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
16 14 12 10 8 6
ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

Plate 42


SPEED IN MPH
16
14
12
10
8
6
ENGINE RPM IN PERCENT OF MAXIMUM
100
80
60
40
20
0
10000
20000
30000
40000
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED
ENGINE RPM AND SPEED
840' X 138' X 43' SHIP
530,000-CFS FLOW
UPSTREAM RUNS

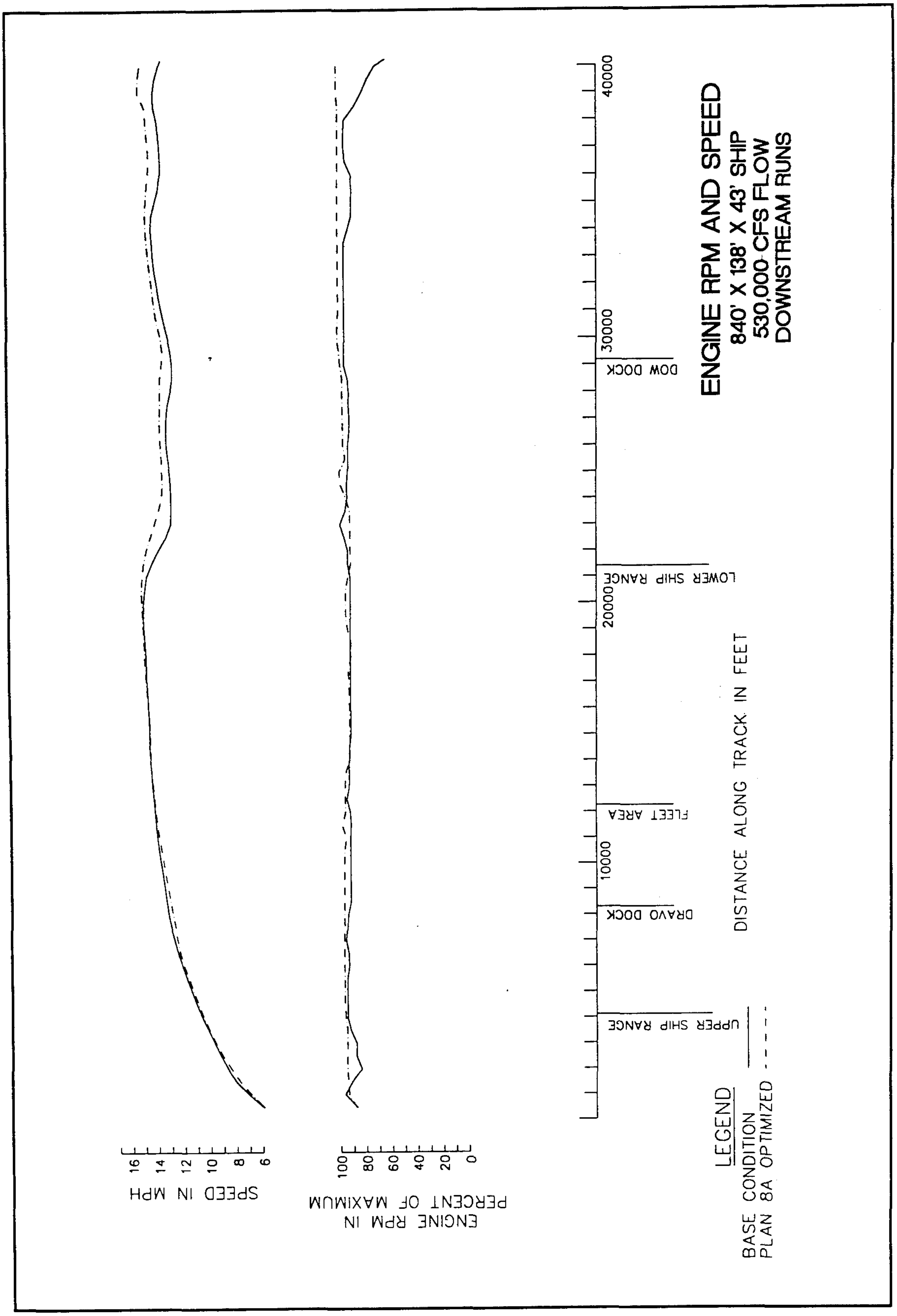
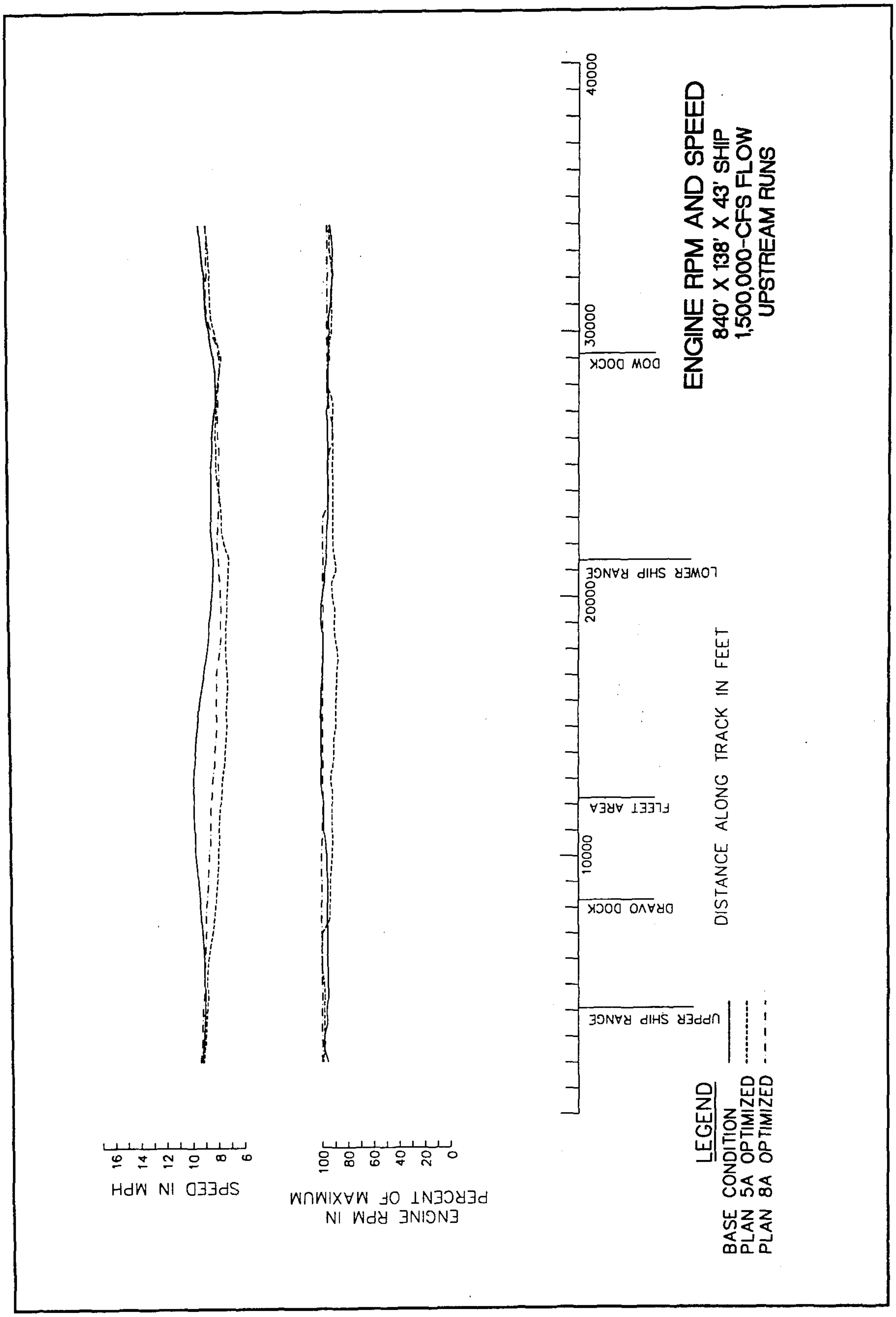
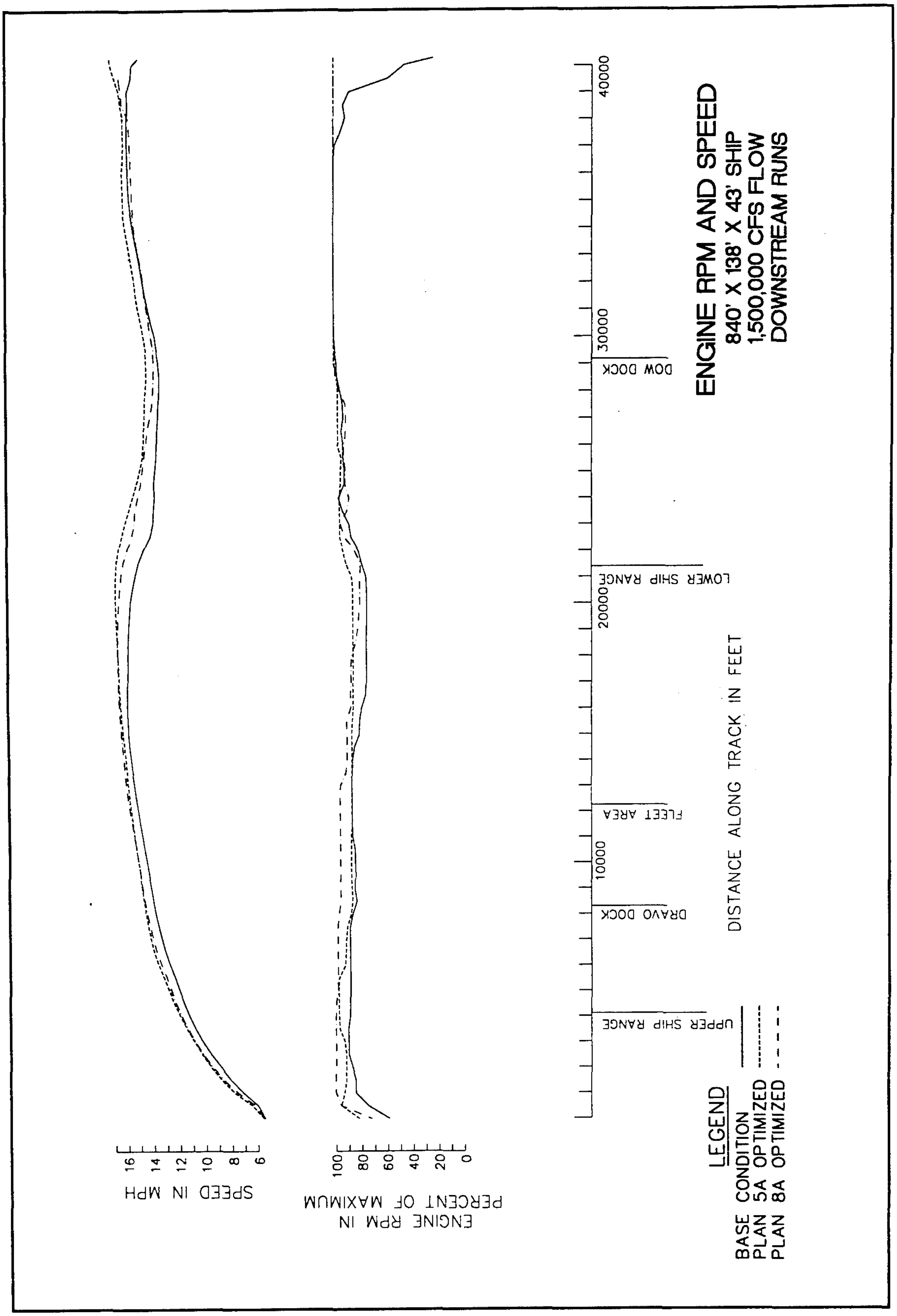
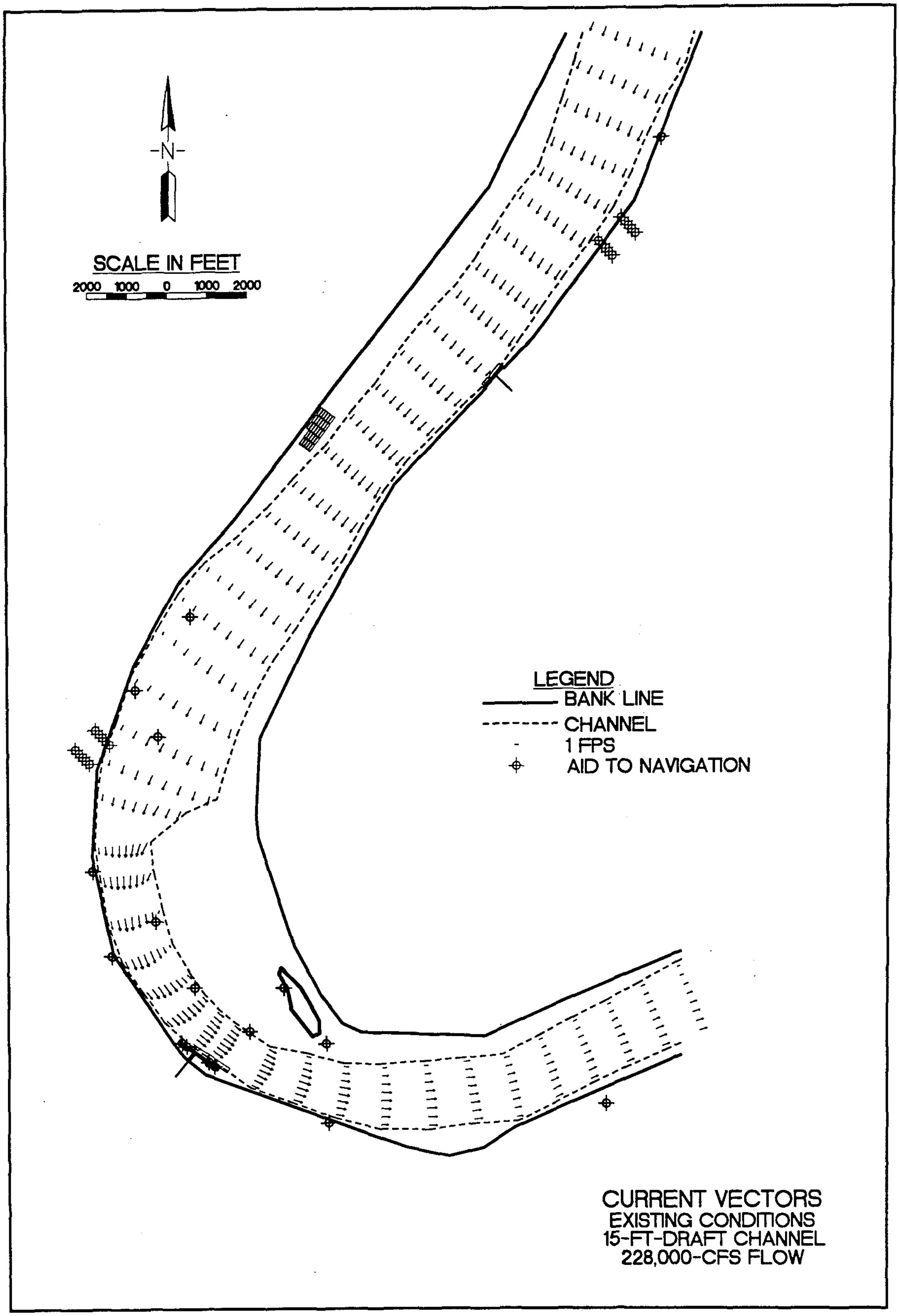

ENGINE RPM AND SPEED
840' X 138' X 43' SHIP
530,000-CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
6
8
10
12
14
16
ENGINE RPM IN PERCENT OF MAXIMUM
0
20
40
60
80
100
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED

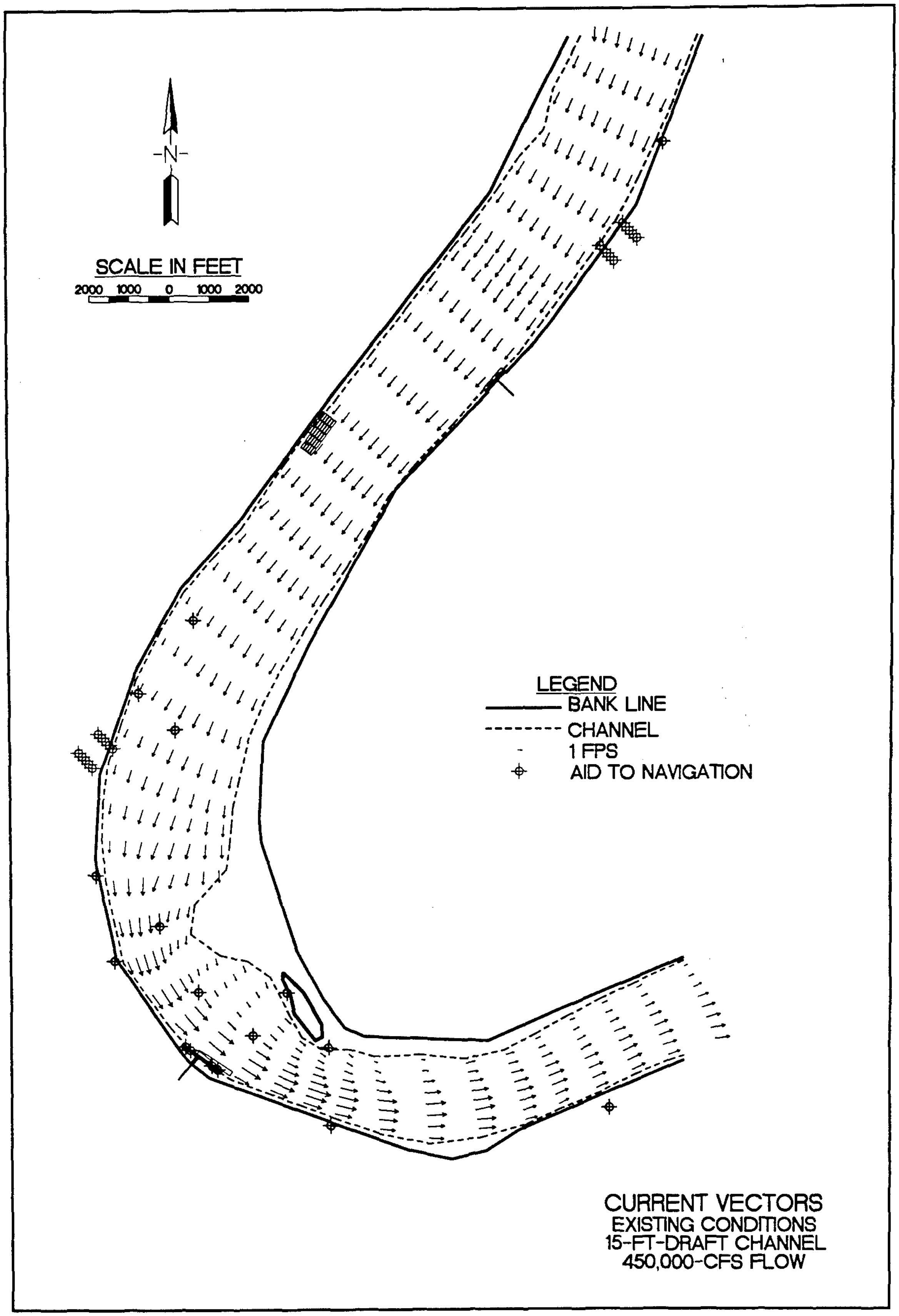
Plate 44


ENGINE RPM AND SPEED
840' X 138' X 43' SHIP
1,500,000-CFS FLOW
UPSTREAM RUNS
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED
PLAN 8A OPTIMIZED
SPEED IN MPH
16 14 12 10 8 6
ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
DISTANCE ALONG TRACK IN FEET
10000 20000 30000 40000
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK


ENGINE RPM AND SPEED
840' X 138' X 43' SHIP
1,500,000 CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
16
14
12
10
8
6
ENGINE RPM IN PERCENT OF MAXIMUM
100
80
60
40
20
0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED
PLAN 8A OPTIMIZED



-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AID TO NAVIGATION
CURRENT VECTORS
EXISTING CONDITIONS
15-FT-DRAFT CHANNEL
228,000-CFS FLOW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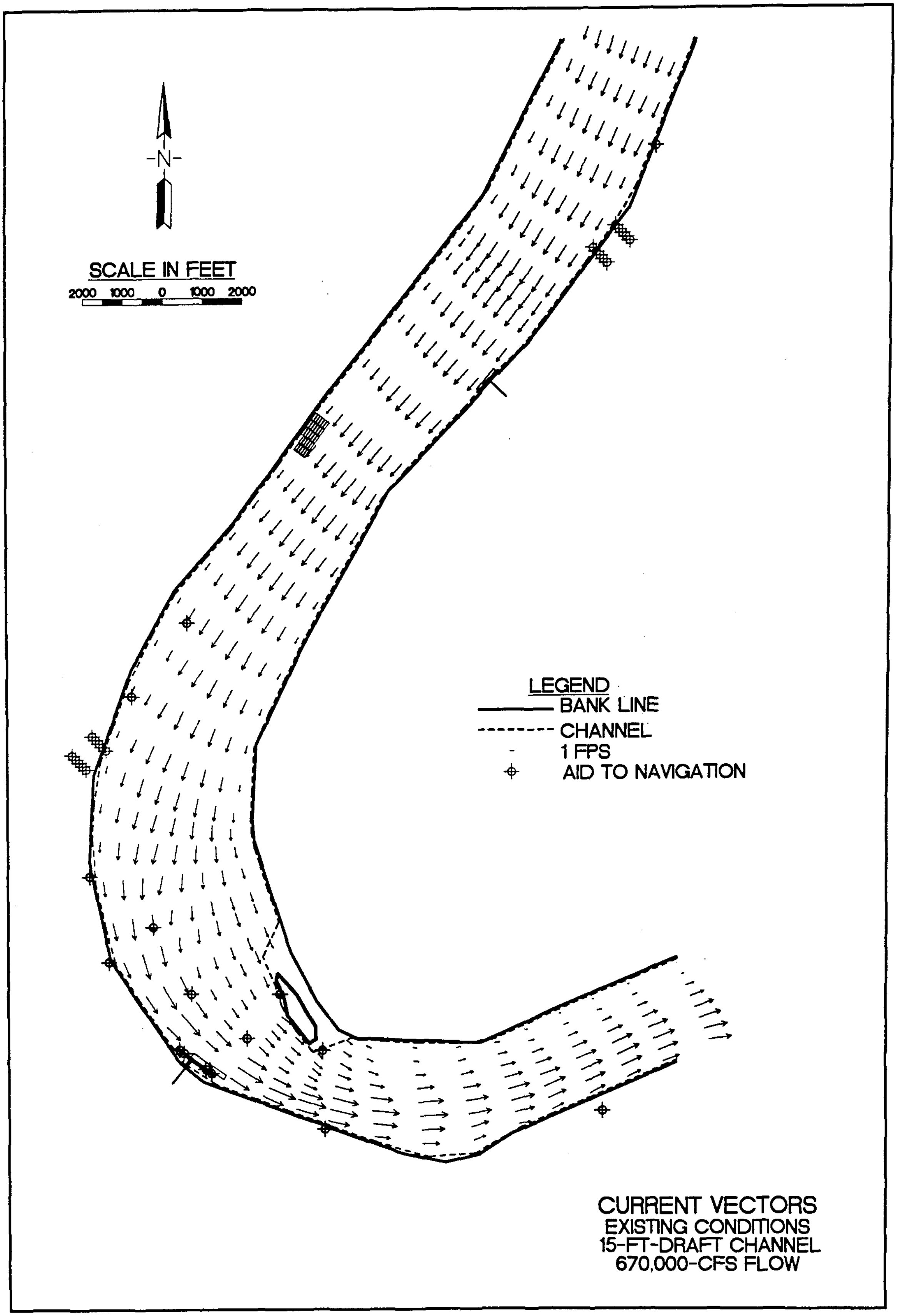
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AID TO NAVIGATION
CURRENT VECTORS
EXISTING CONDITIONS
15-FT-DRAFT CHANNEL
450,000-CFS FLOW


N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AID TO NAVIGATION
CURRENT VECTORS
EXISTING CONDITIONS
15-FT-DRAFT CHANNEL
670,000-CFS FLOW

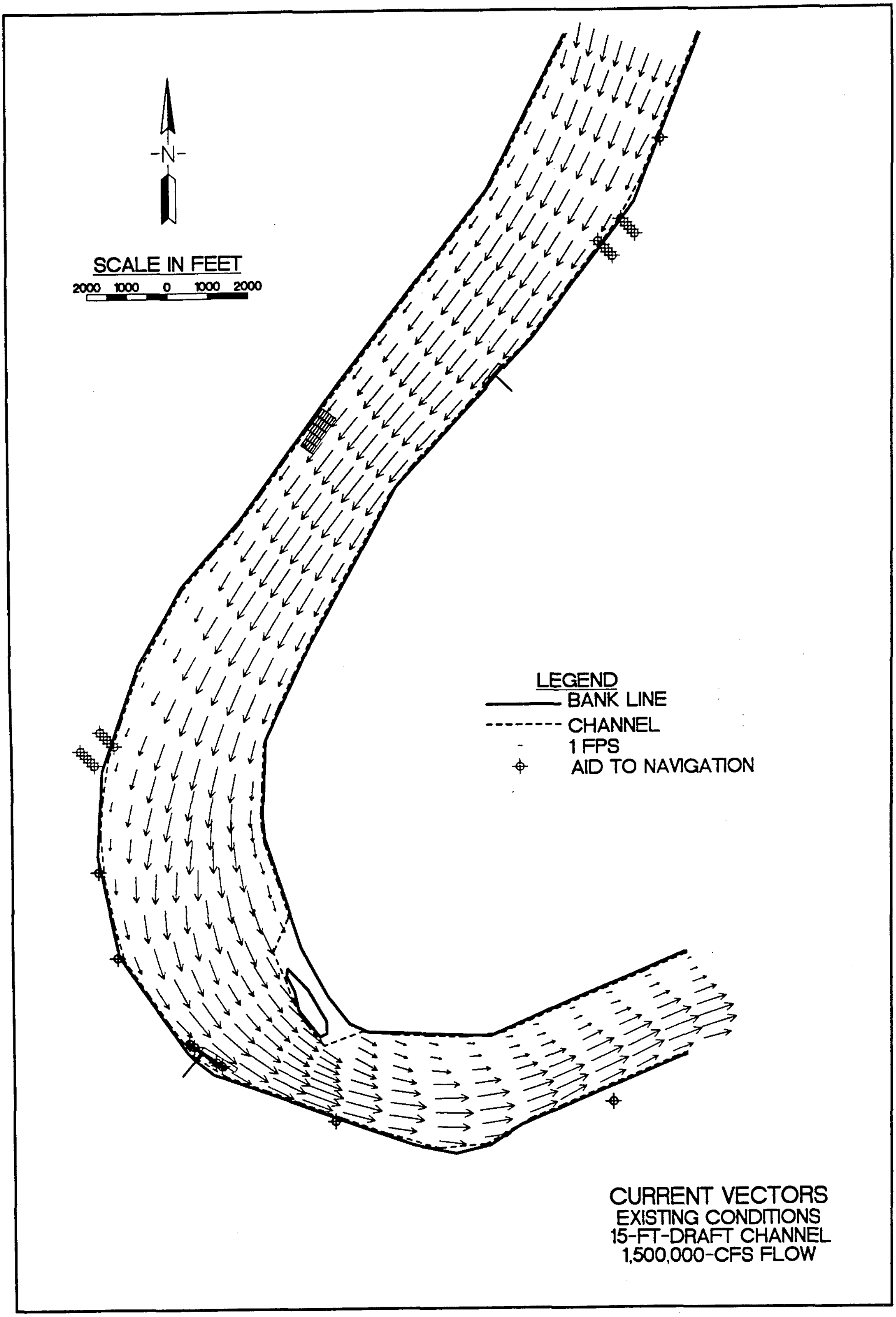
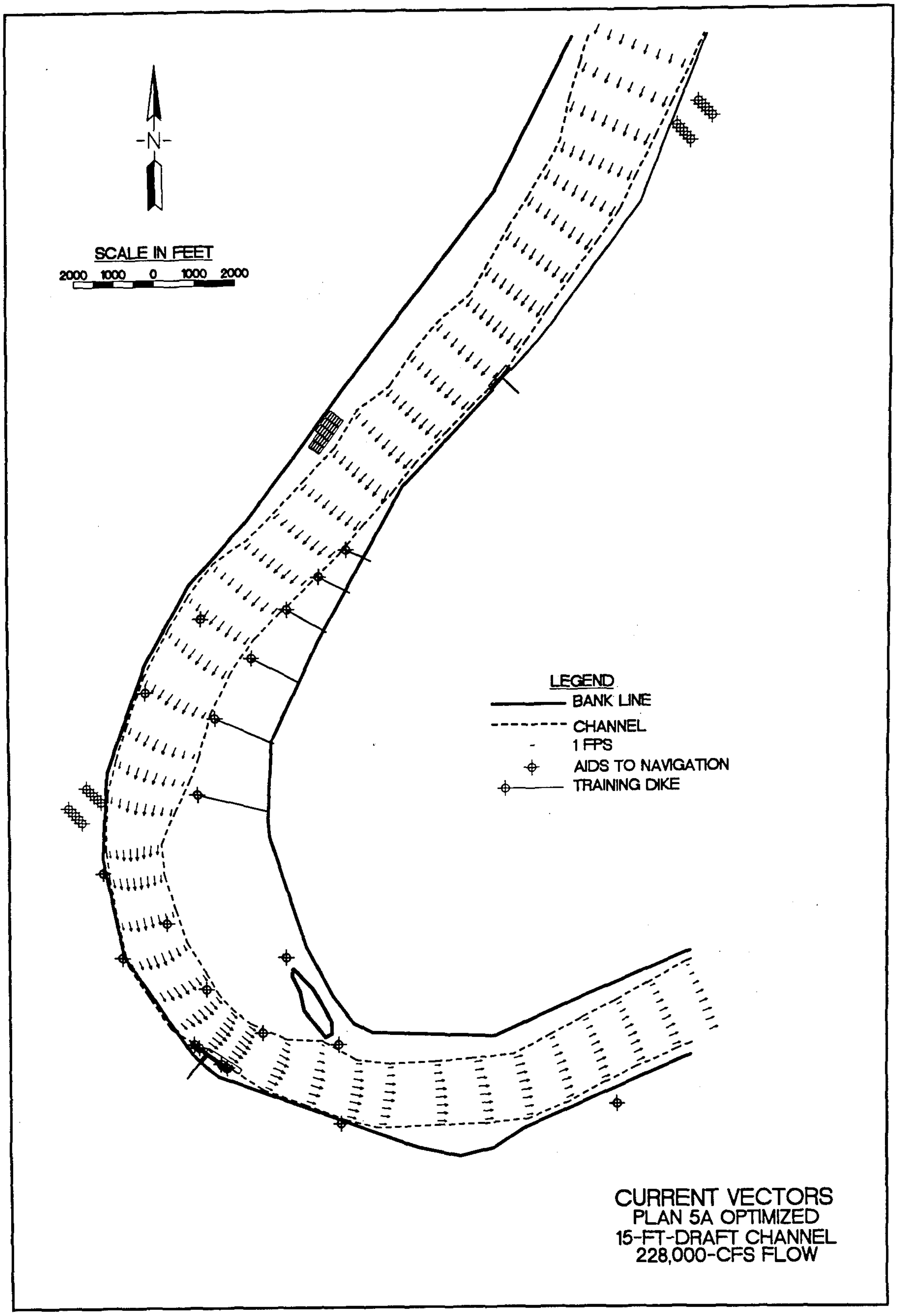
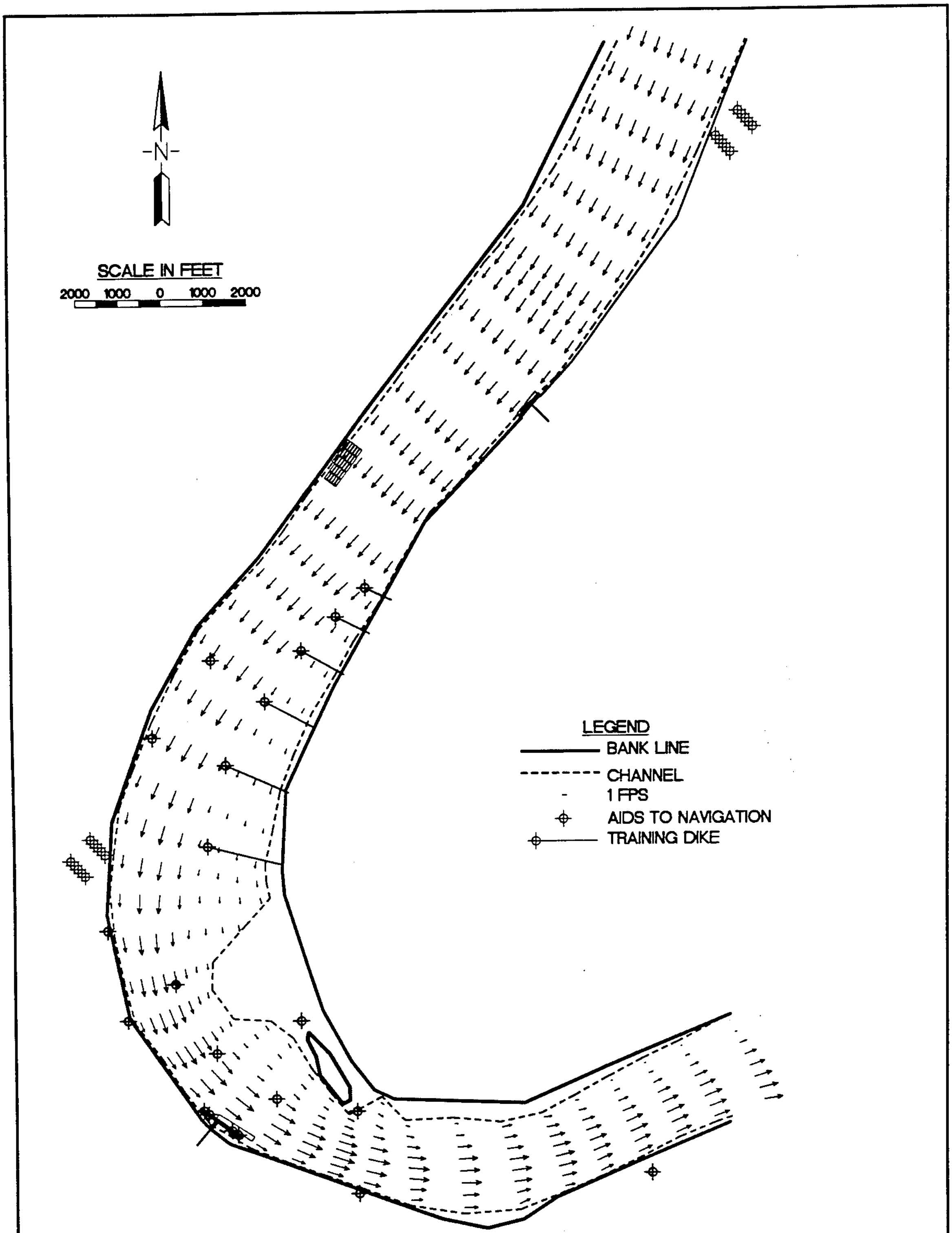
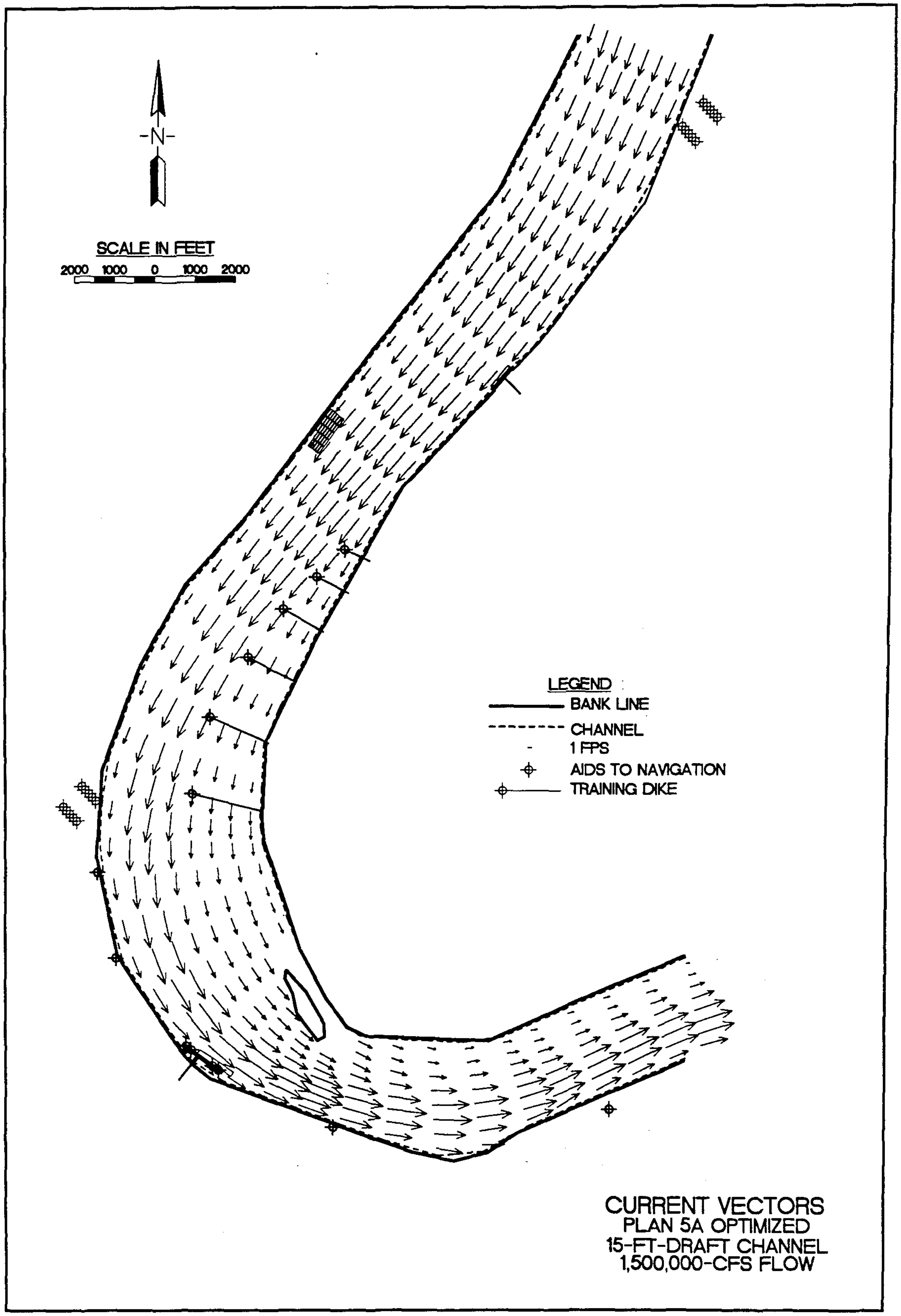

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AID TO NAVIGATION
CURRENT VECTORS
EXISTING CONDITIONS
15-FT-DRAFT CHANNEL
1,500,000-CFS FLOW

Plate 50

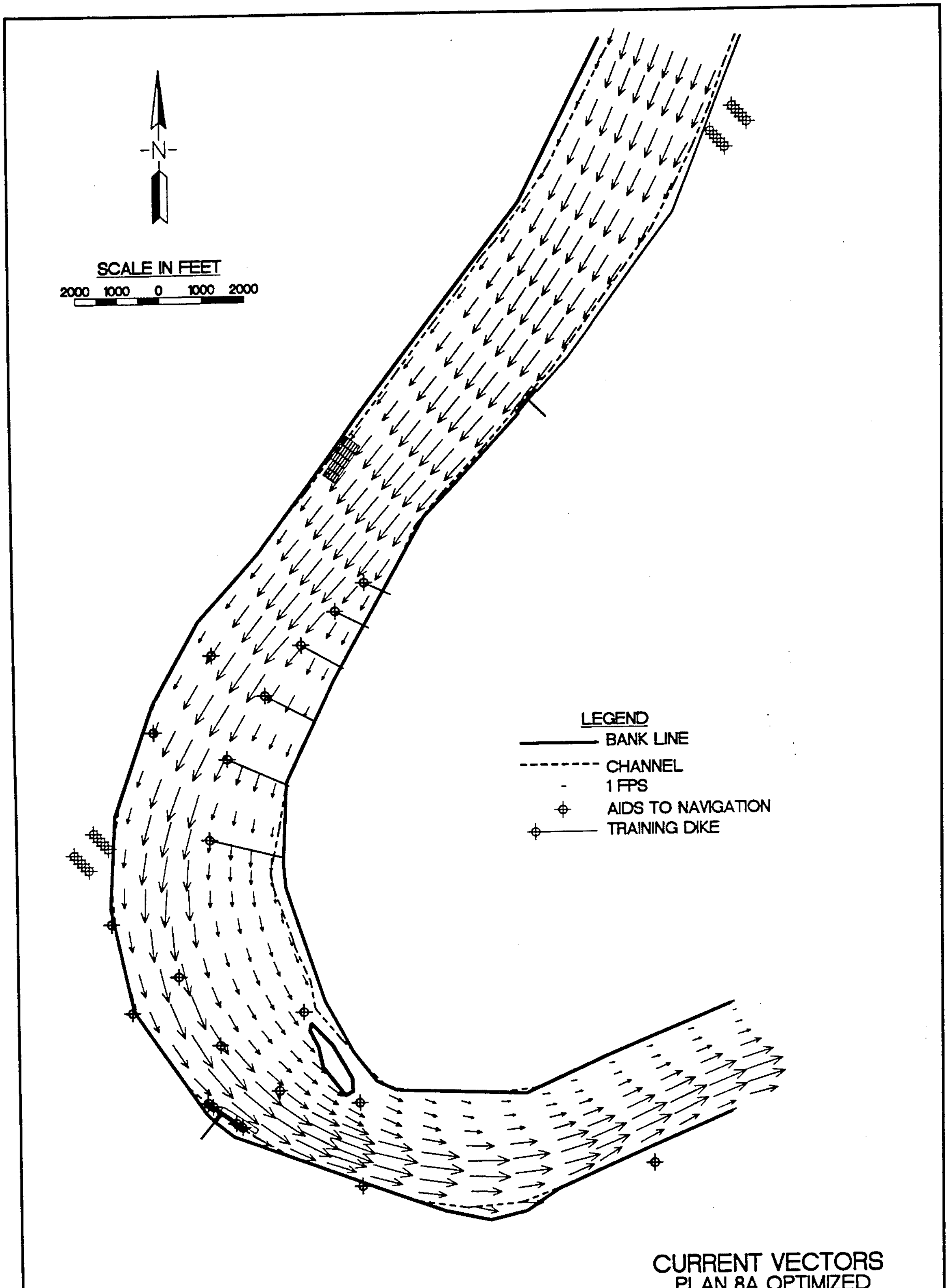

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 5A OPTIMIZED
15-FT-DRAFT CHANNEL
228,000-CFS FLOW



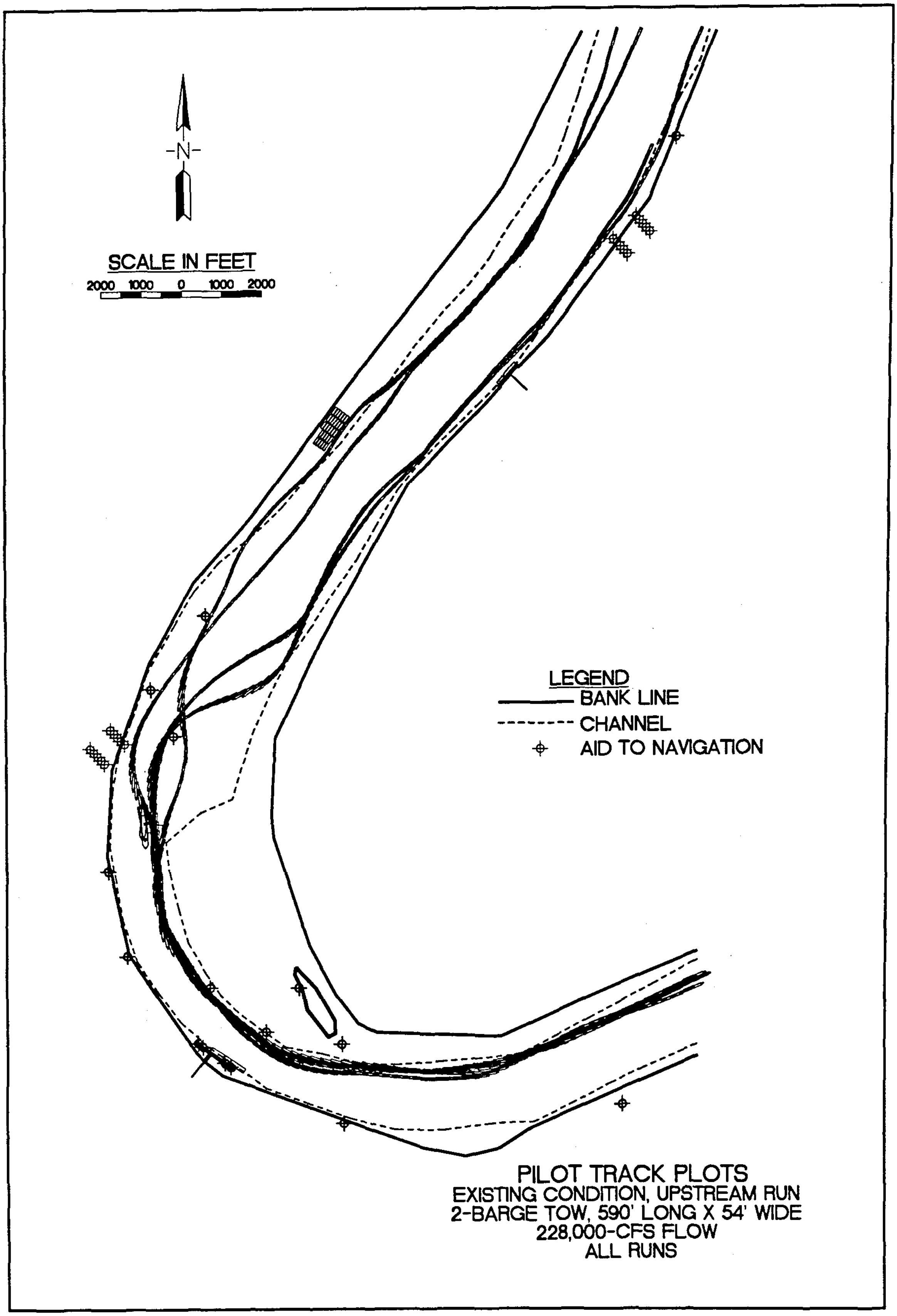
-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 5A OPTIMIZED
15-FT-DRAFT CHANNEL
450,000-CFS FLOW

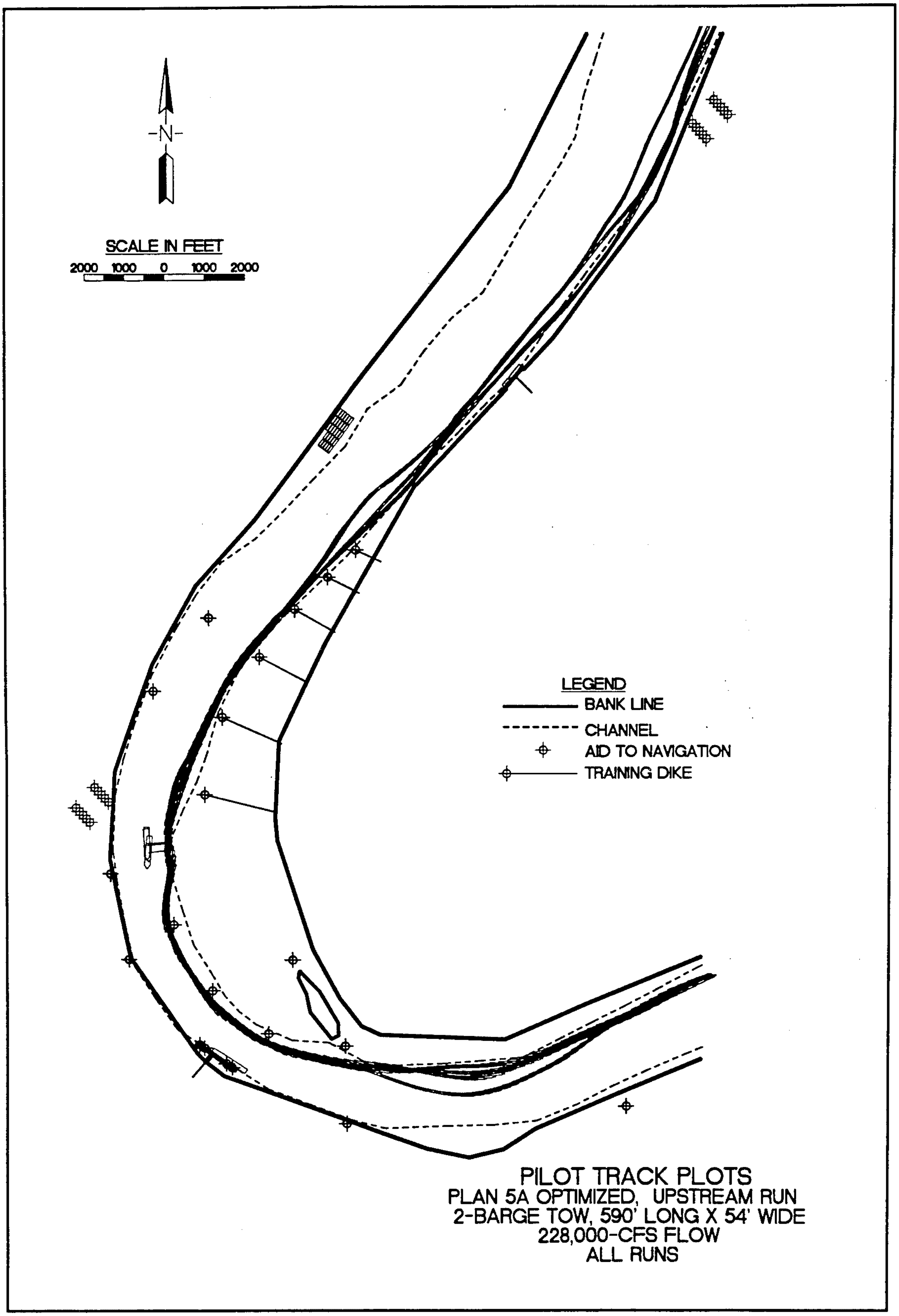


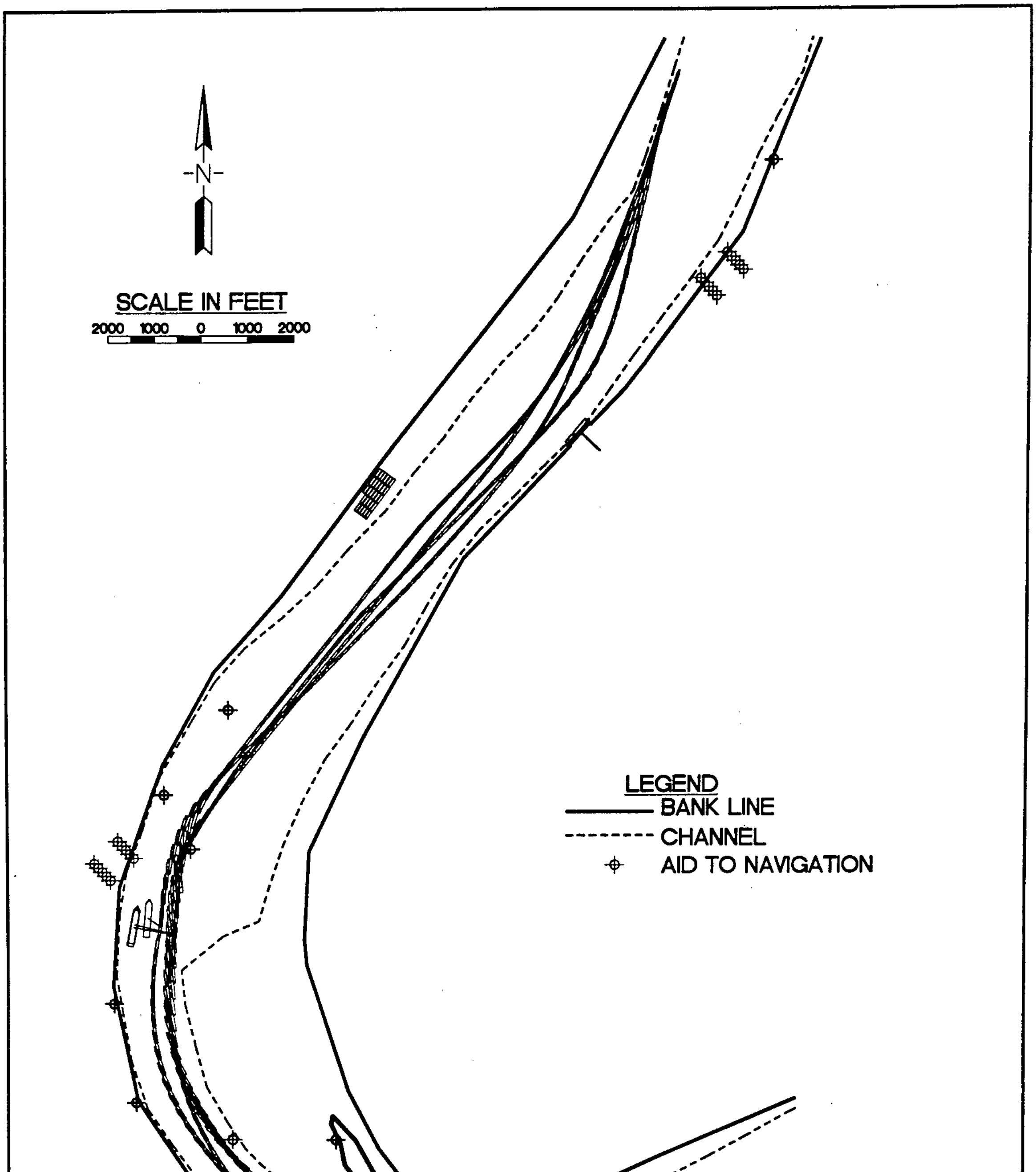
N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 5A OPTIMIZED
15-FT-DRAFT CHANNEL
1,500,000-CFS FLOW

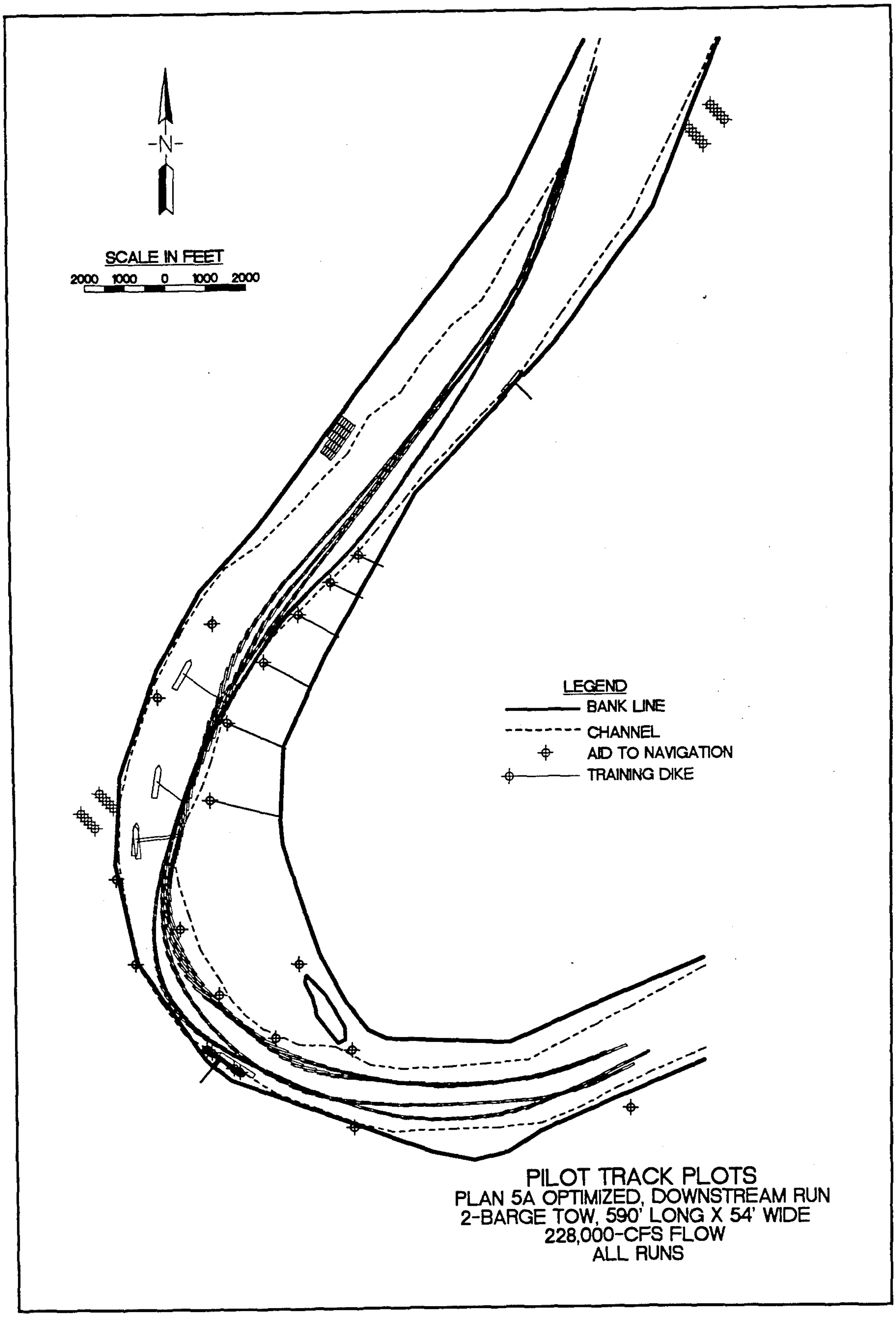


N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 8A OPTIMIZED
15-FT-DRAFT CHANNEL
670,000-CFS FLOW

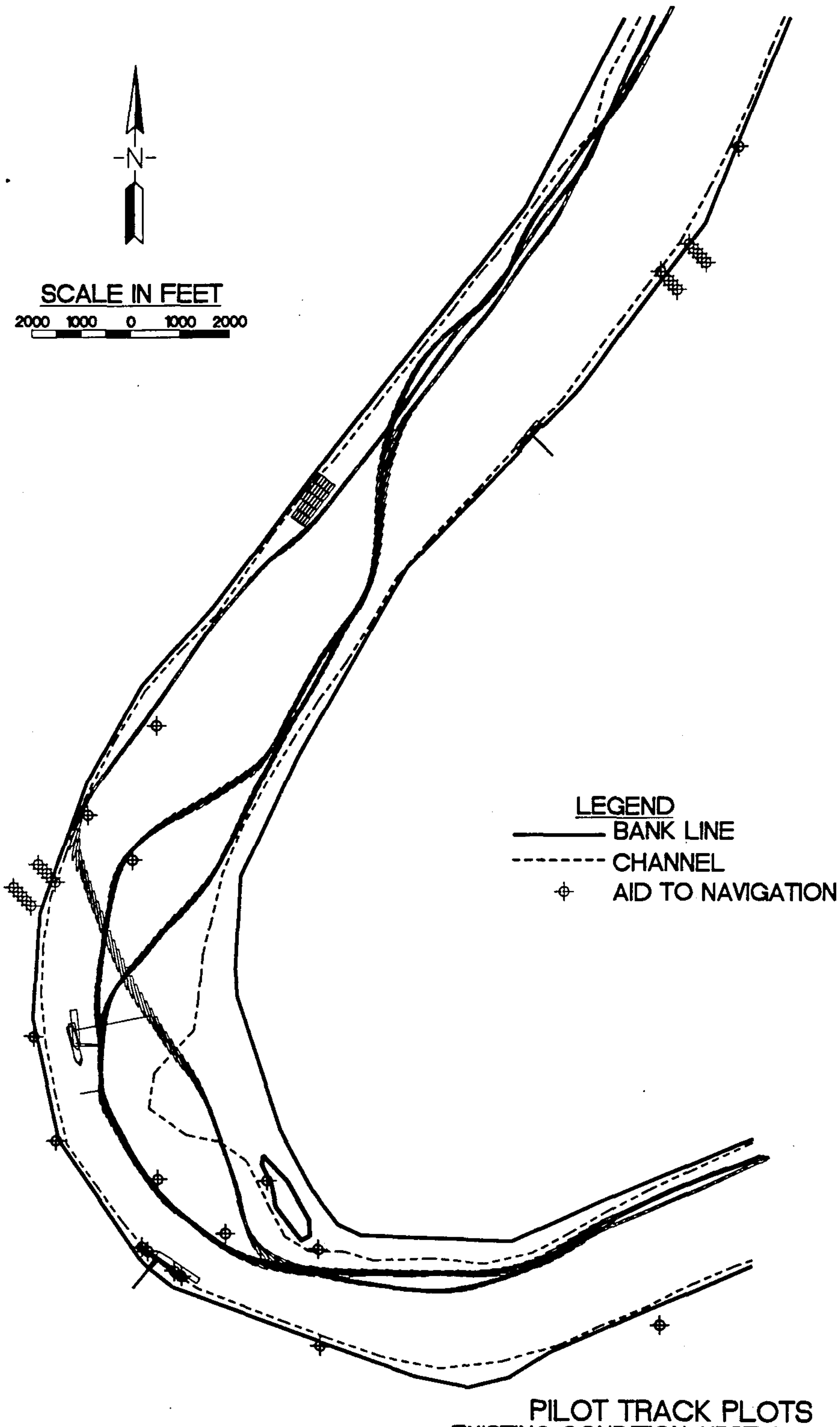

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
228,000-CFS FLOW
ALL RUNS


N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, UPSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
228,000-CFS FLOW
ALL RUNS

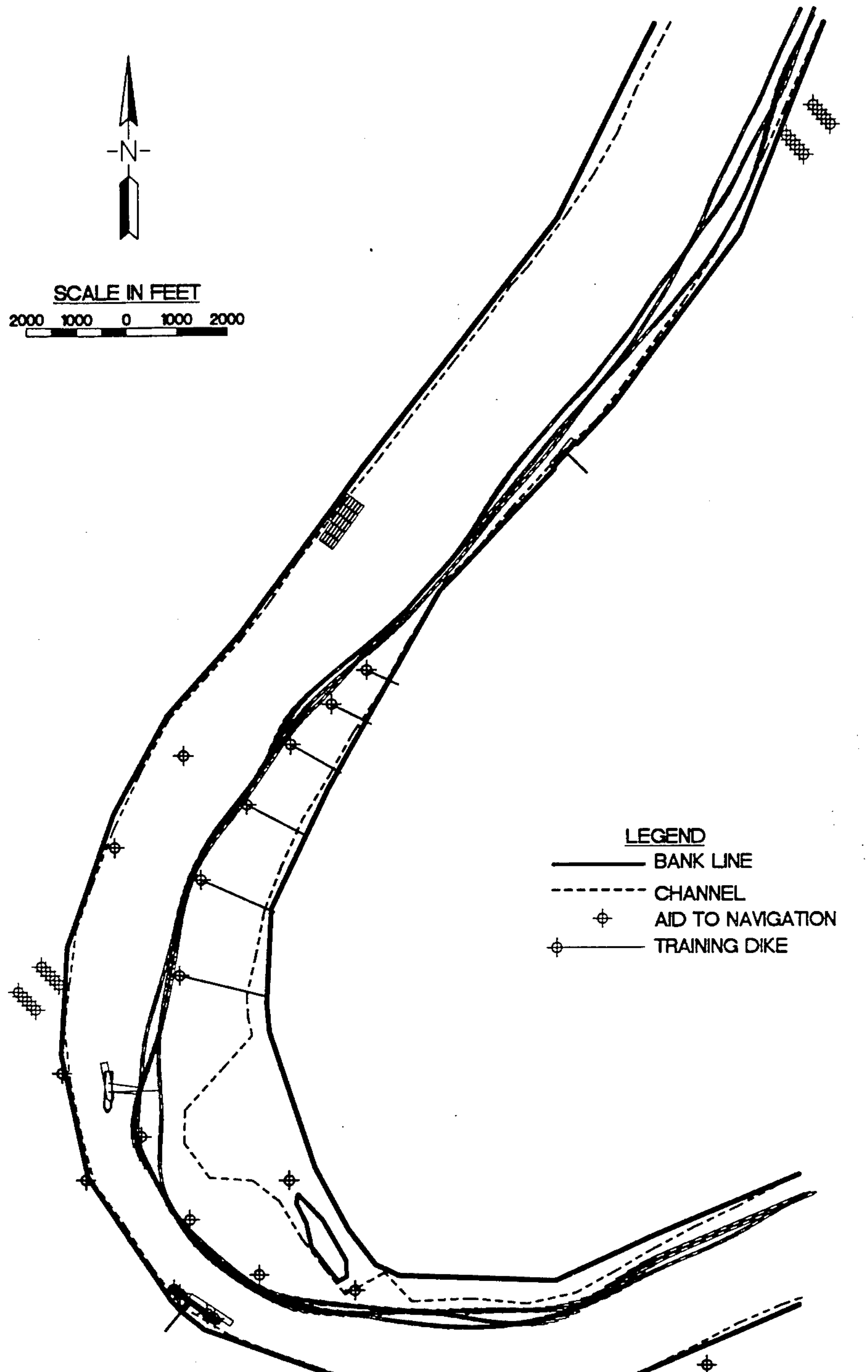

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
228,000-CFS FLOW
ALL RUNS



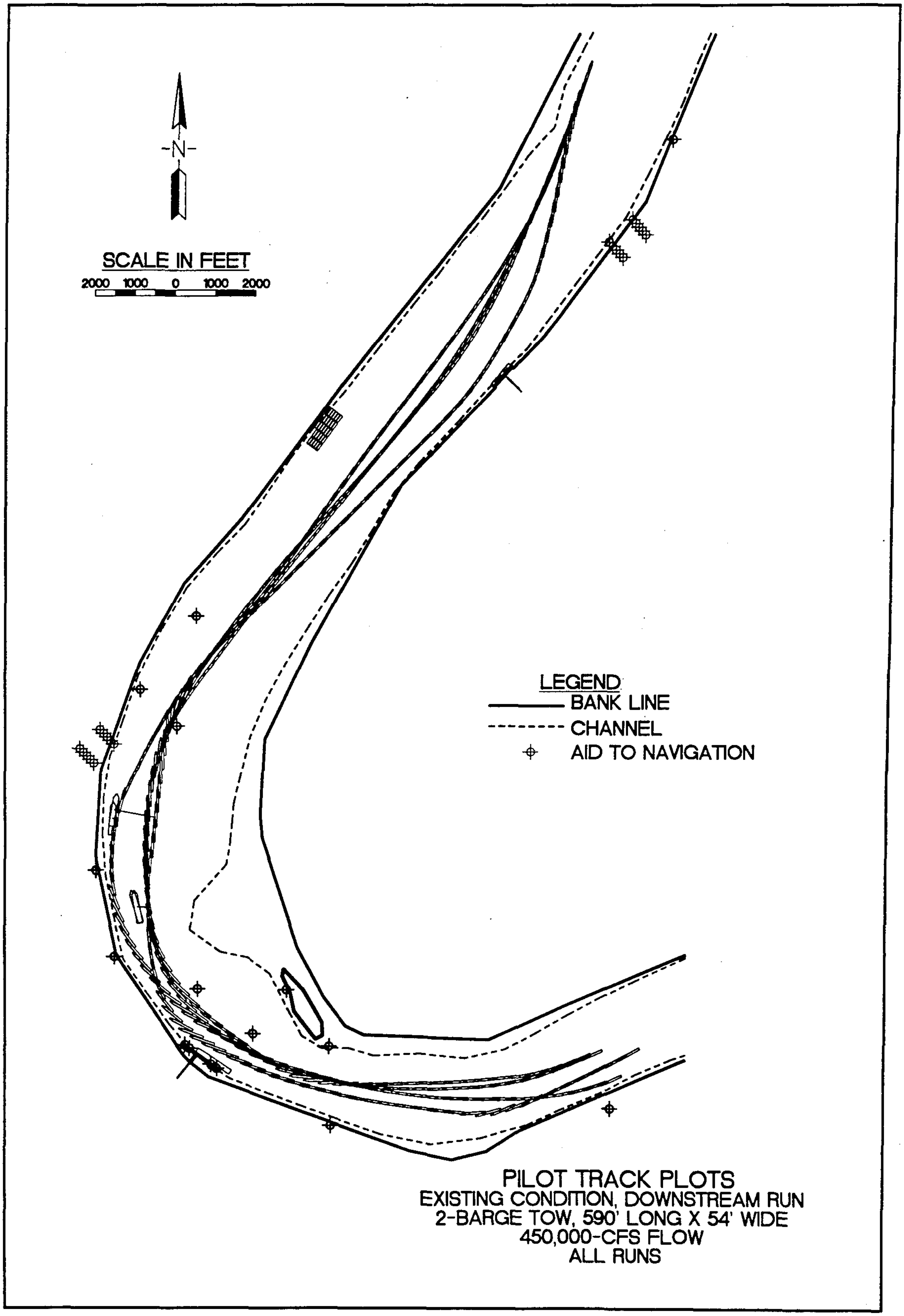
N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, DOWNSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
228,000-CFS FLOW
ALL RUNS



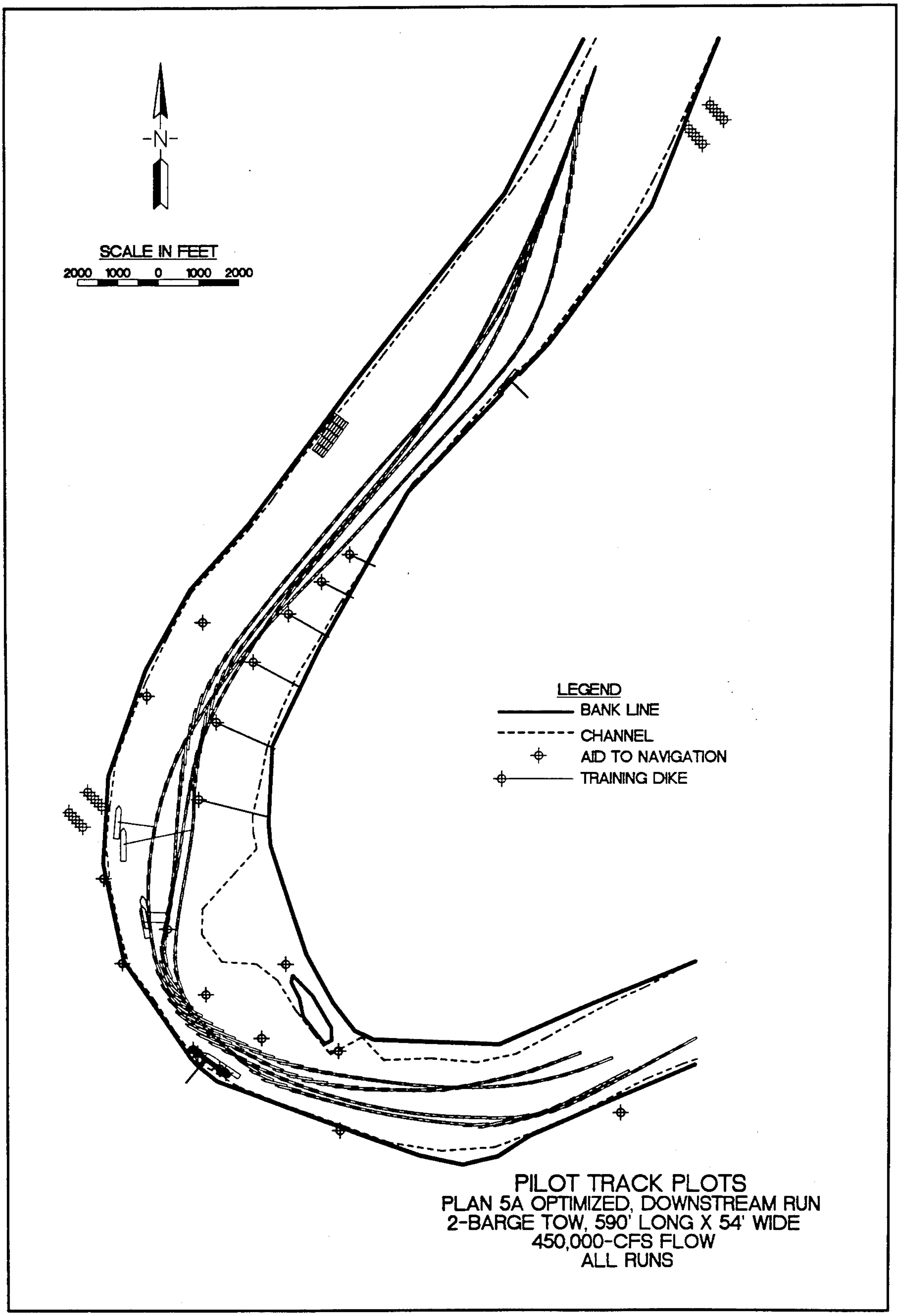

PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
450,000-CFS FLOW
ALL RUNS

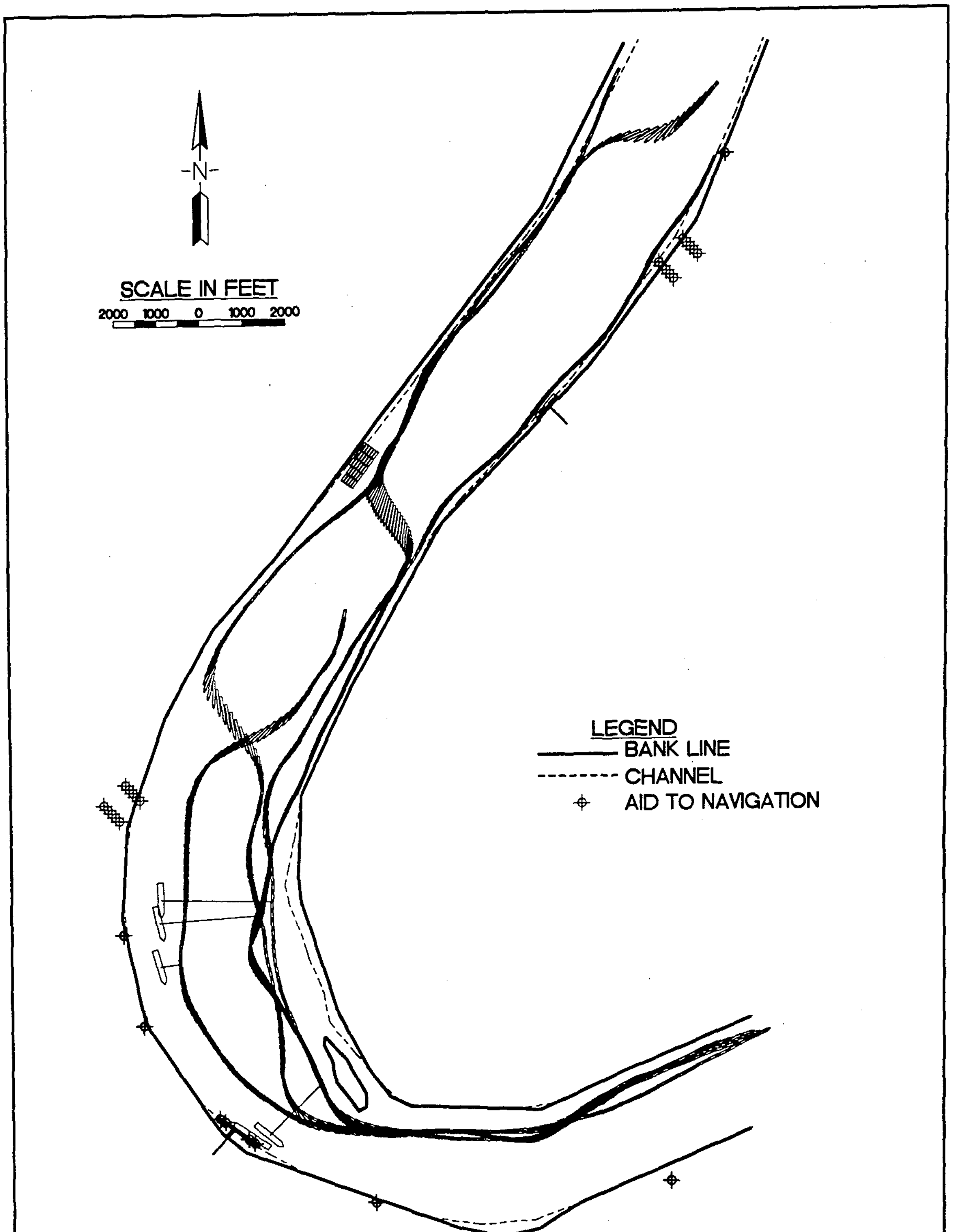



PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, UPSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
450,000-CFS FLOW
ALL RUNS

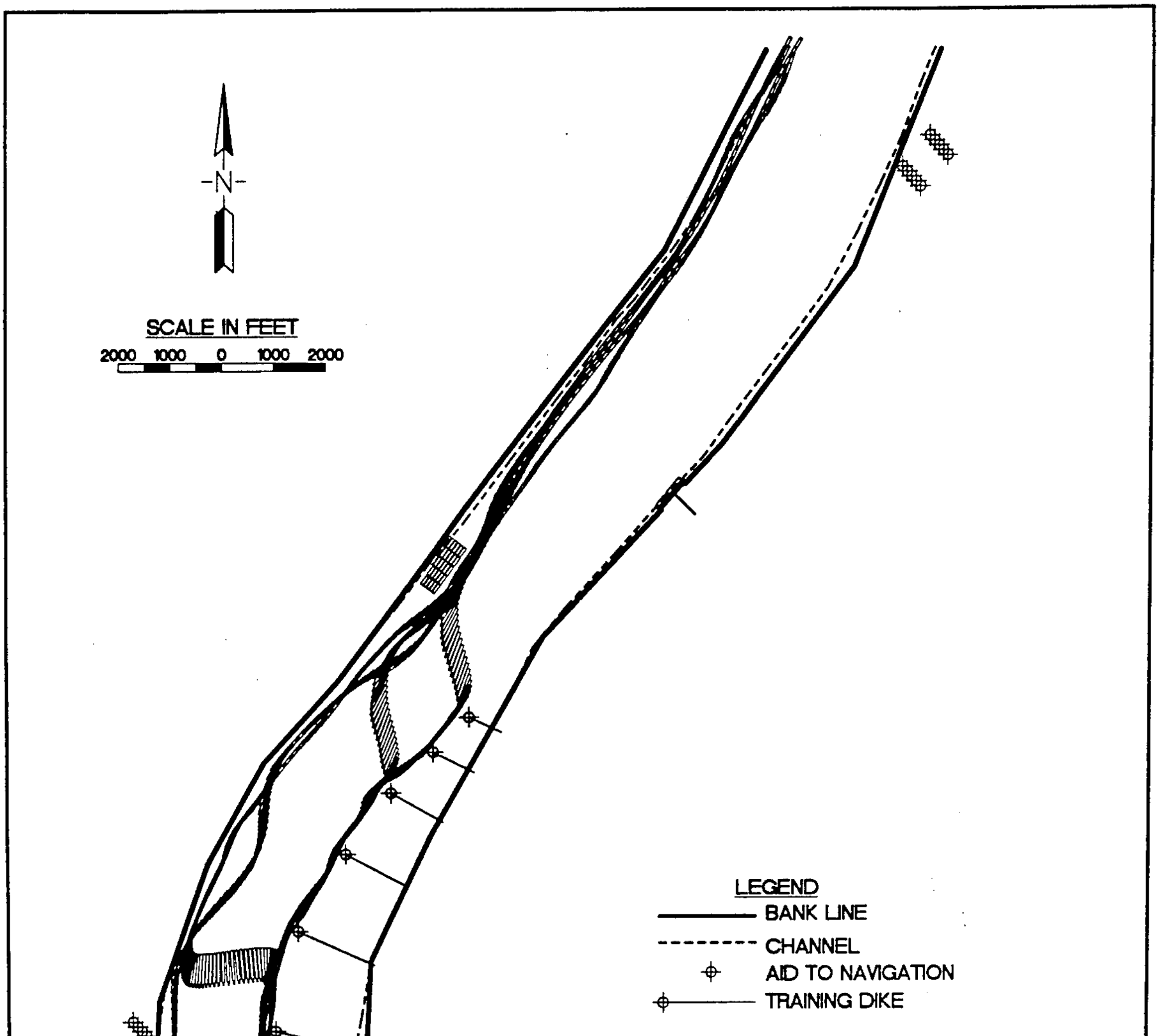


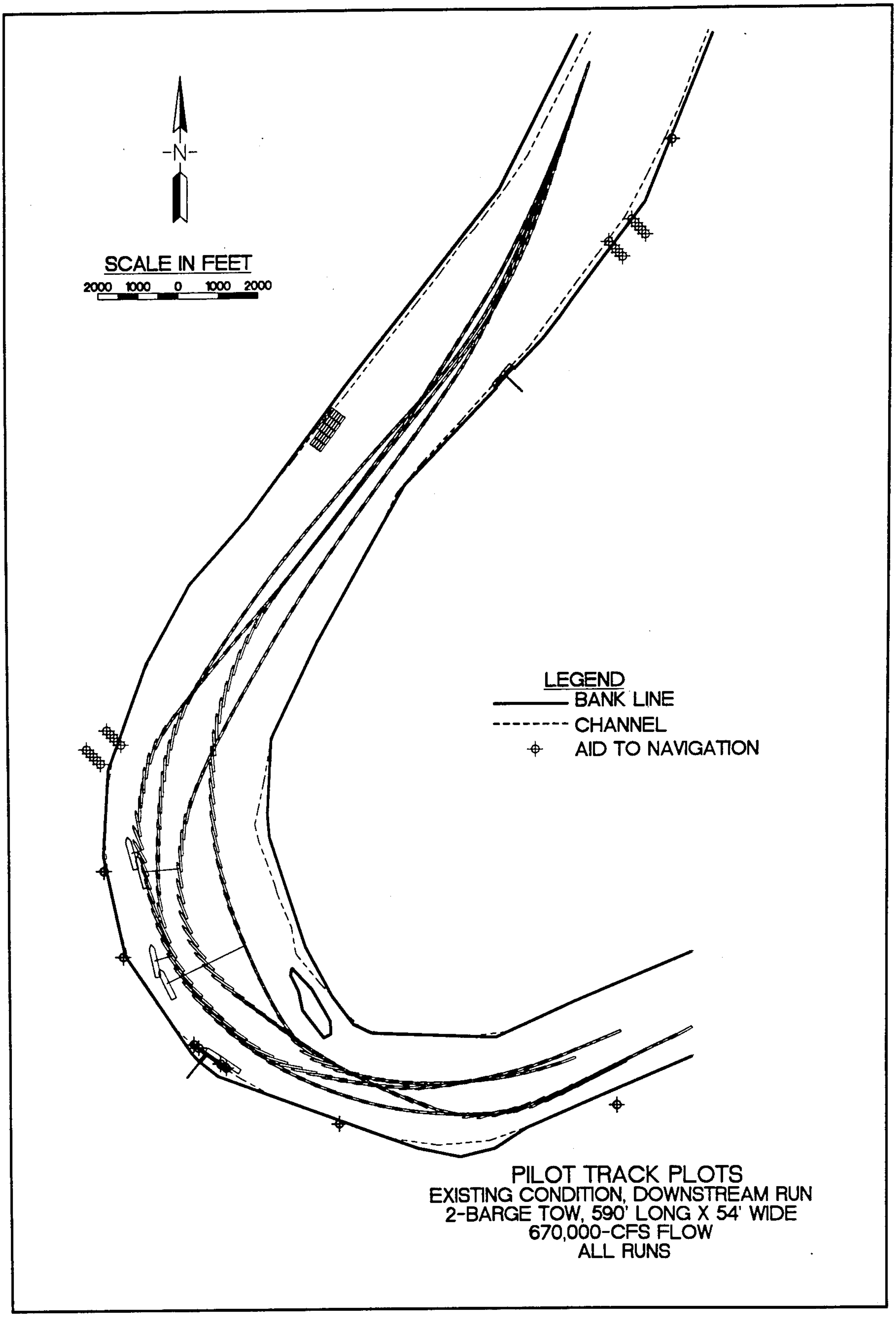
-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
450,000-CFS FLOW
ALL RUNS


N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, DOWNSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
450,000-CFS FLOW
ALL RUNS

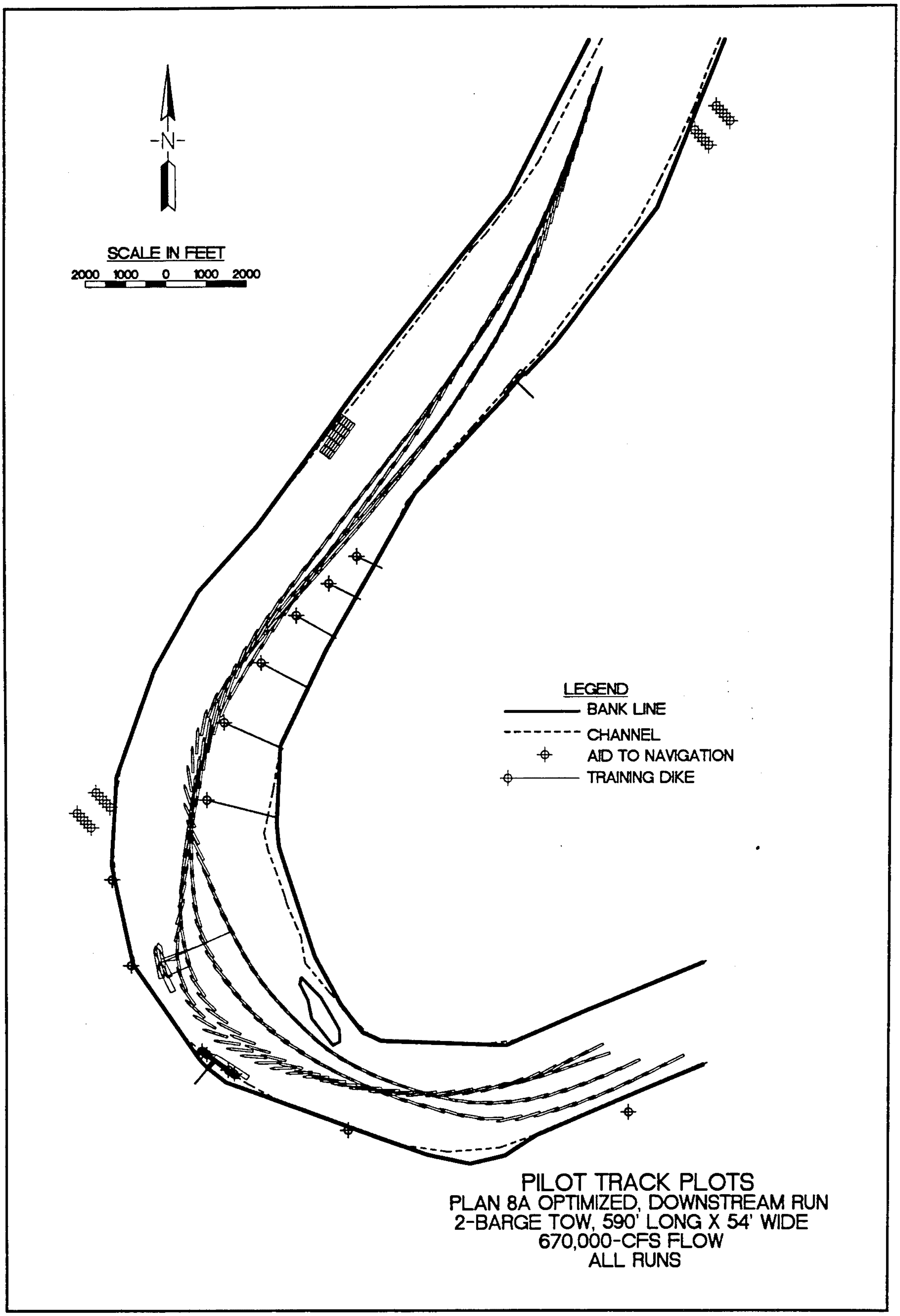


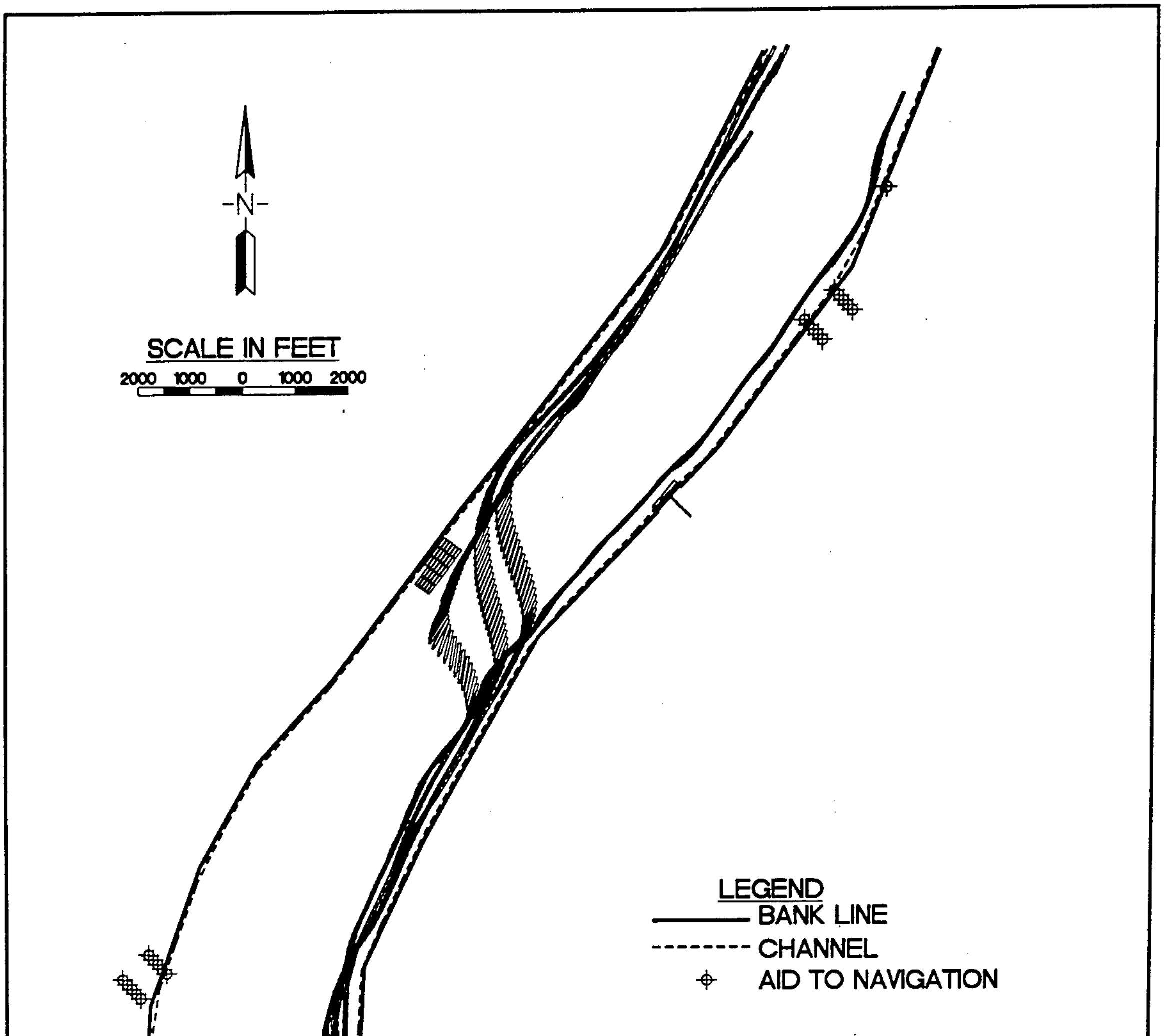

PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
670,000-CFS FLOW
ALL RUNS

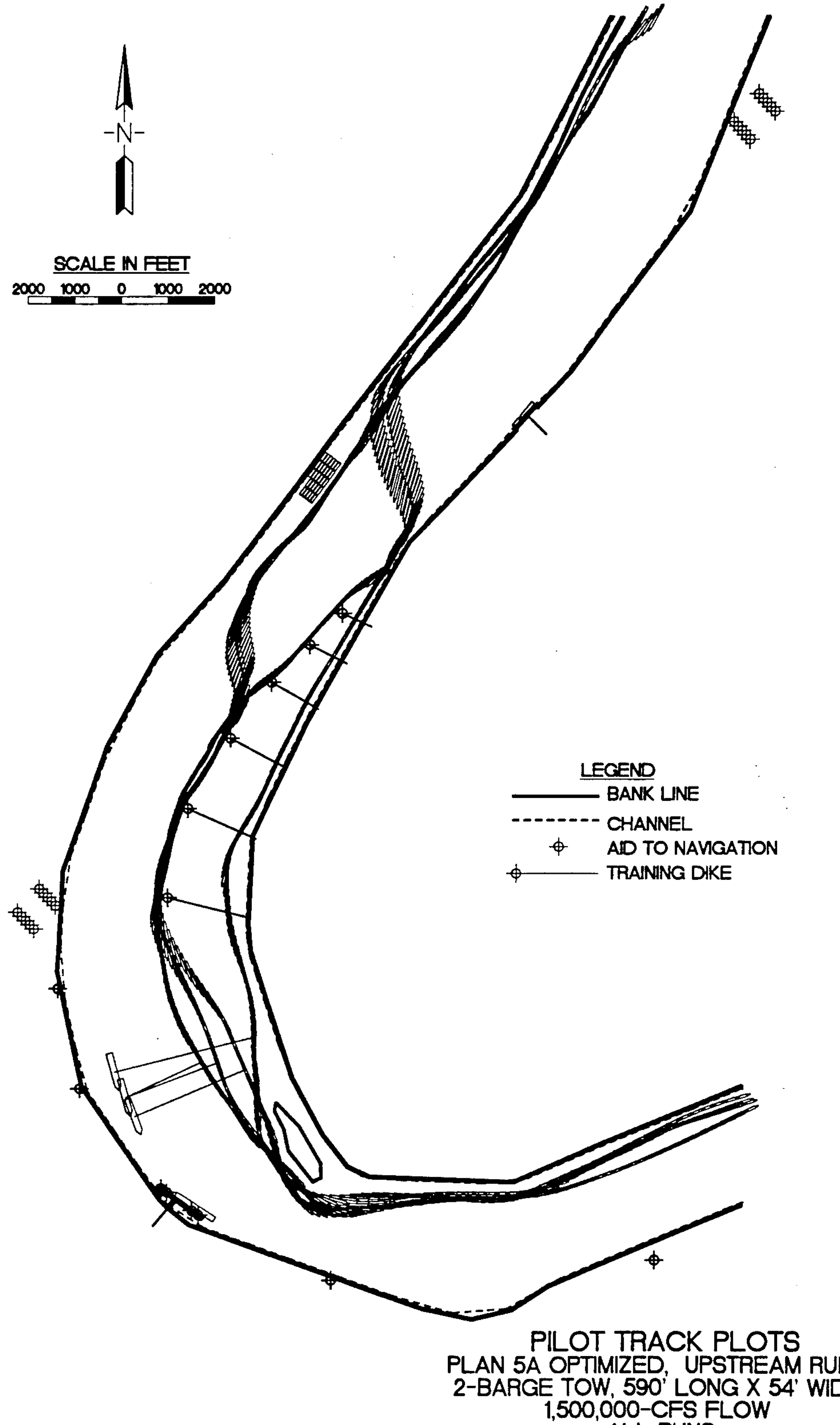

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, UPSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
670,000-CFS FLOW
ALL RUNS



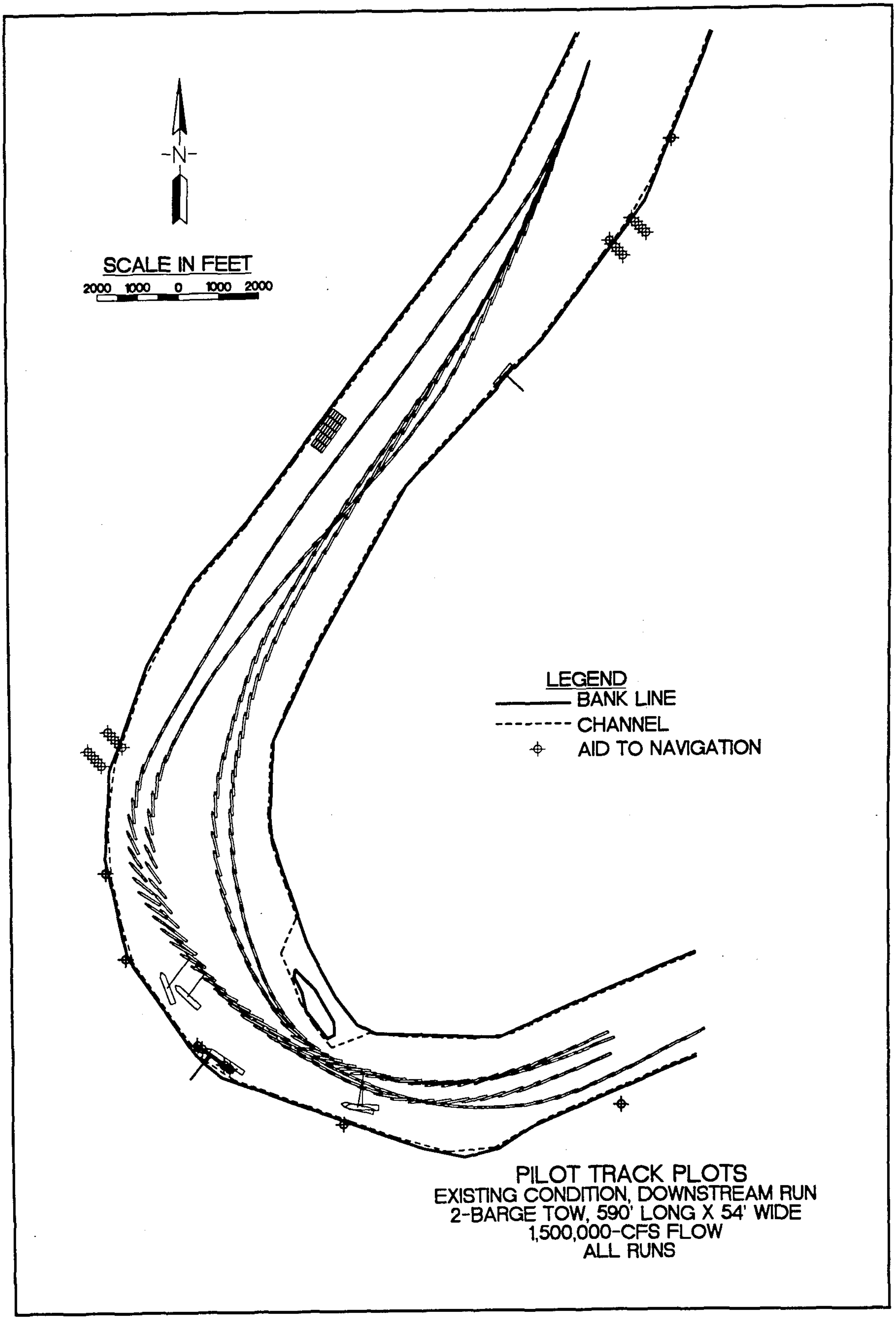
N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
670,000-CFS FLOW
ALL RUNS

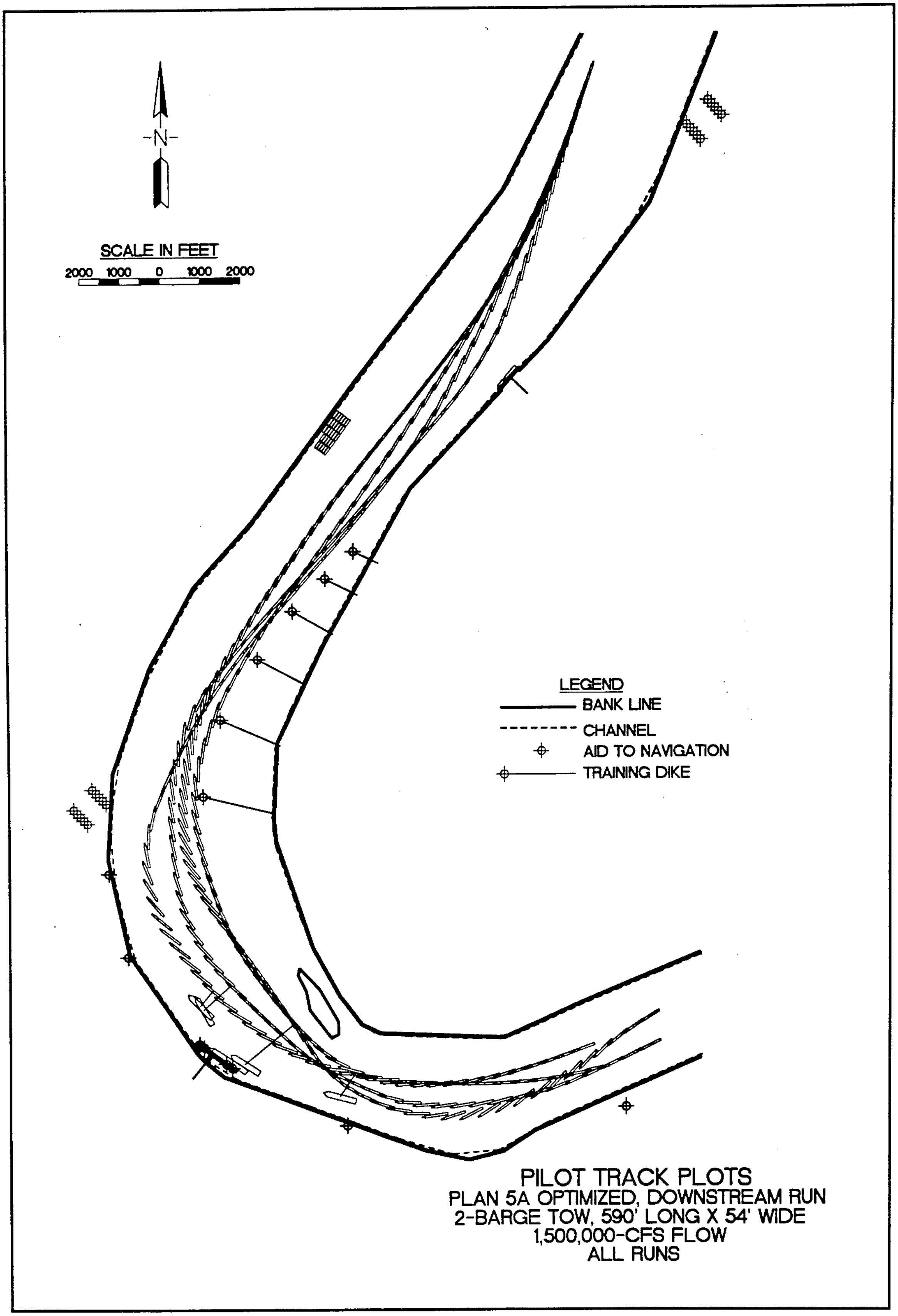

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, DOWNSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
670,000-CFS FLOW
ALL RUNS

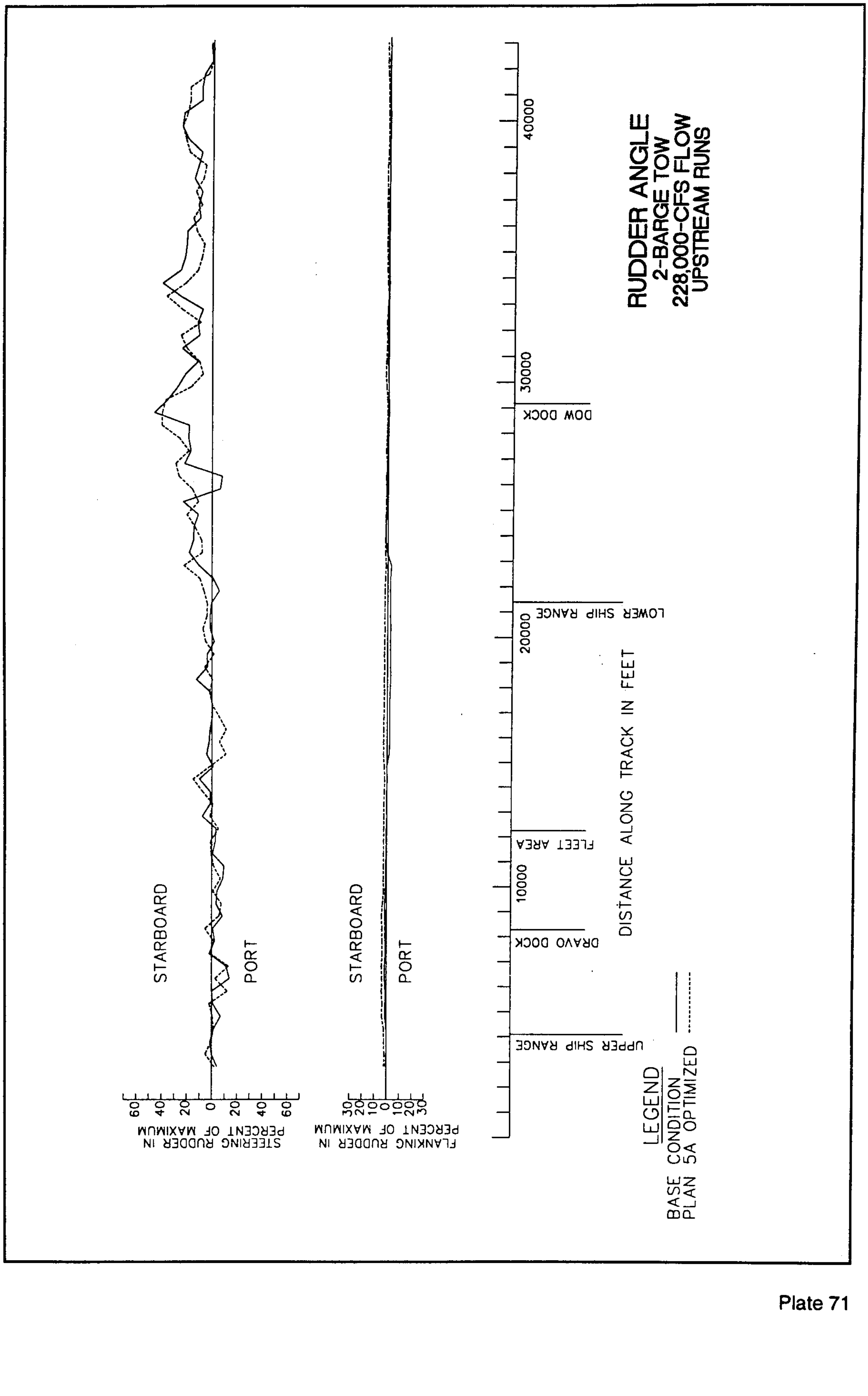

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
1,500,000-CFS FLOW
ALL RUNS

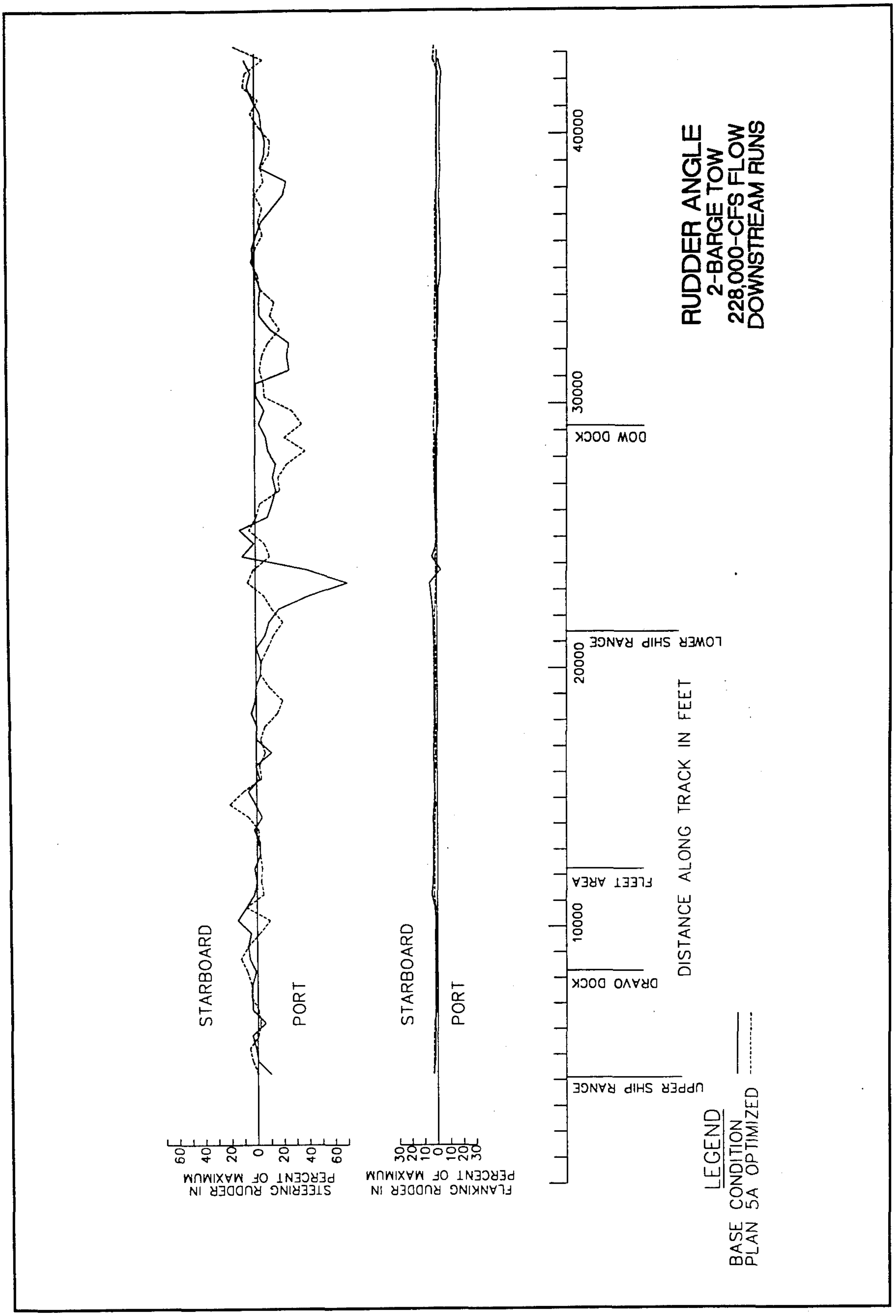


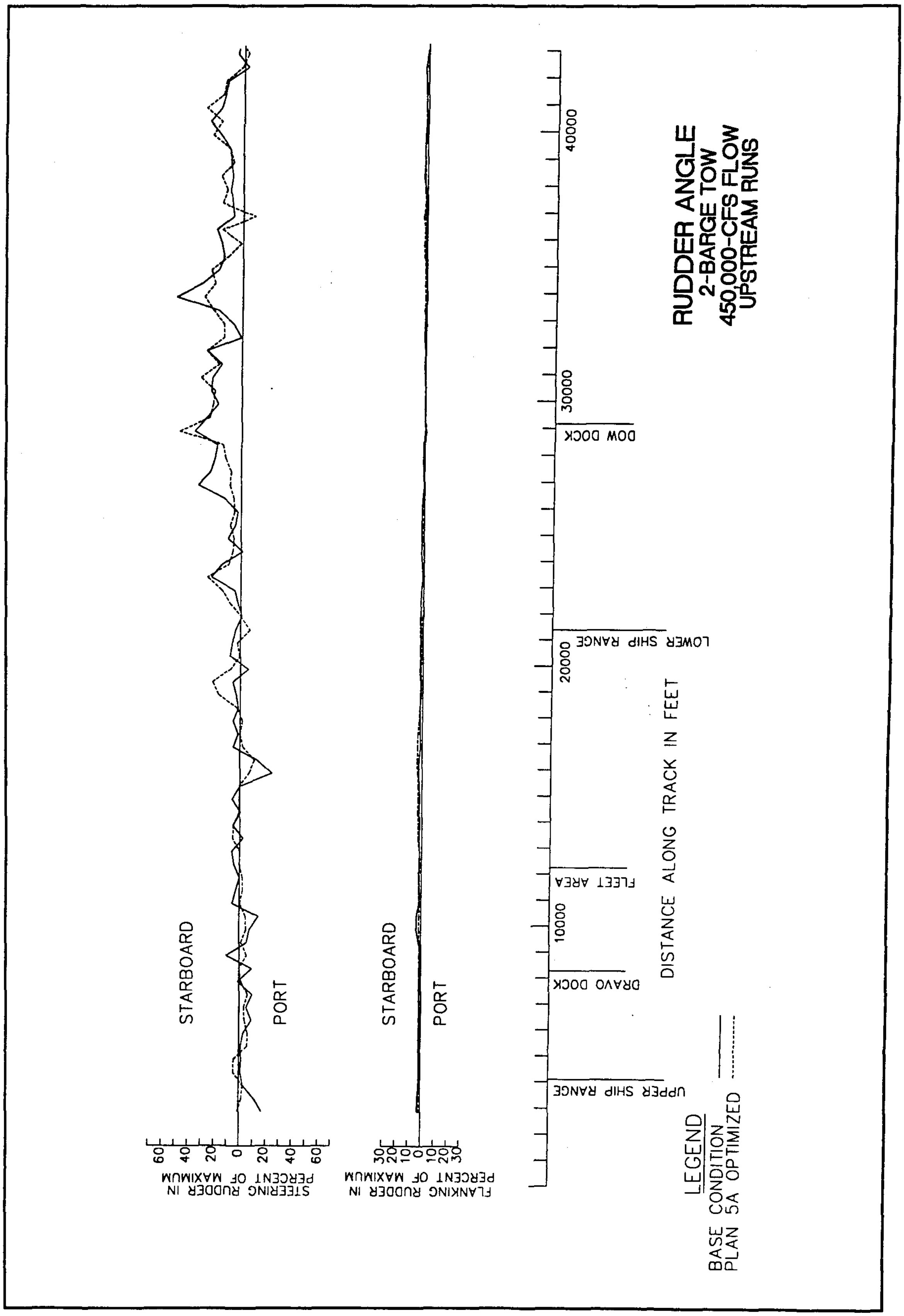

PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, UPSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
1,500,000-CFS FLOW
ALL RUNS

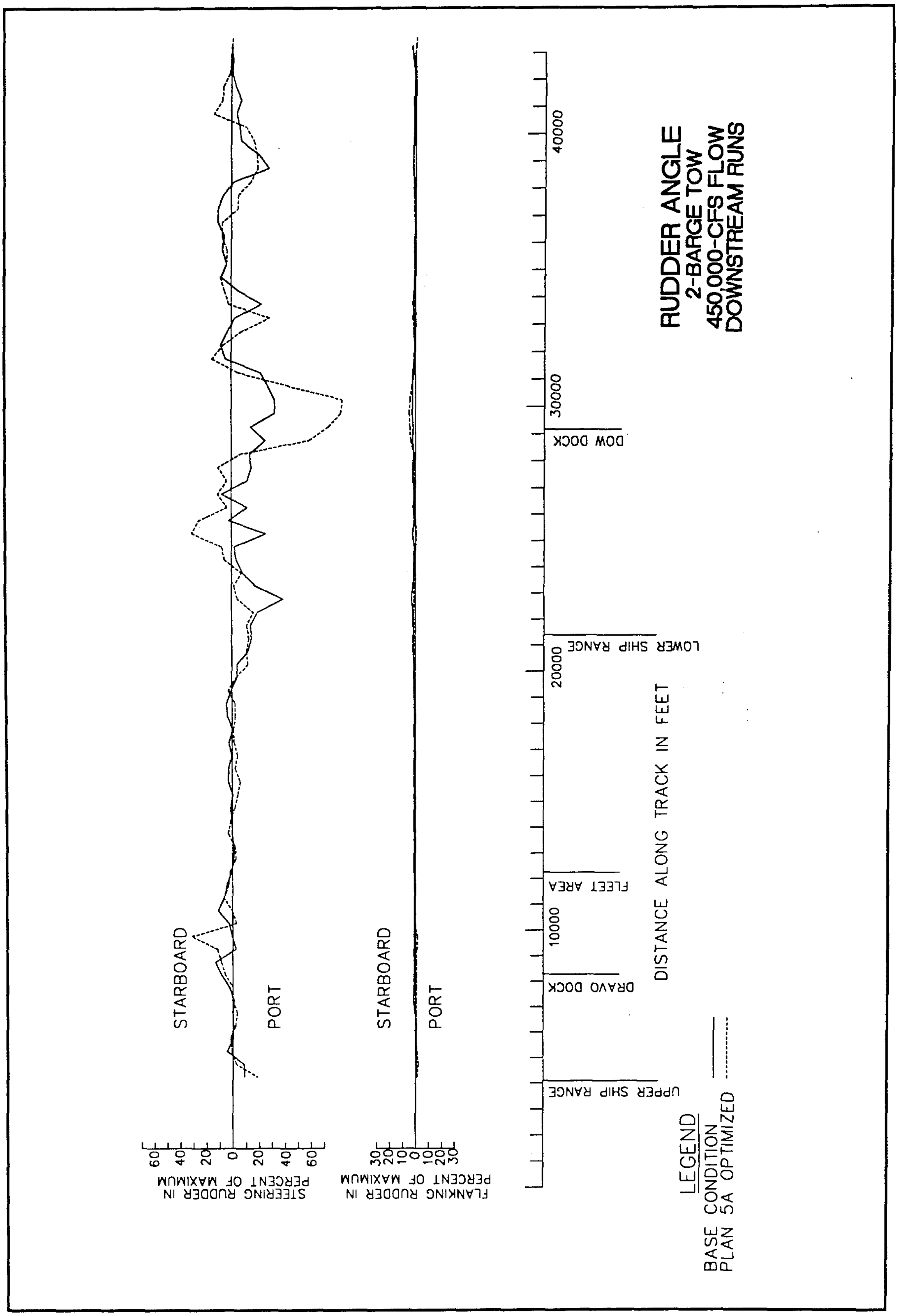

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
1,500,000-CFS FLOW
ALL RUNS

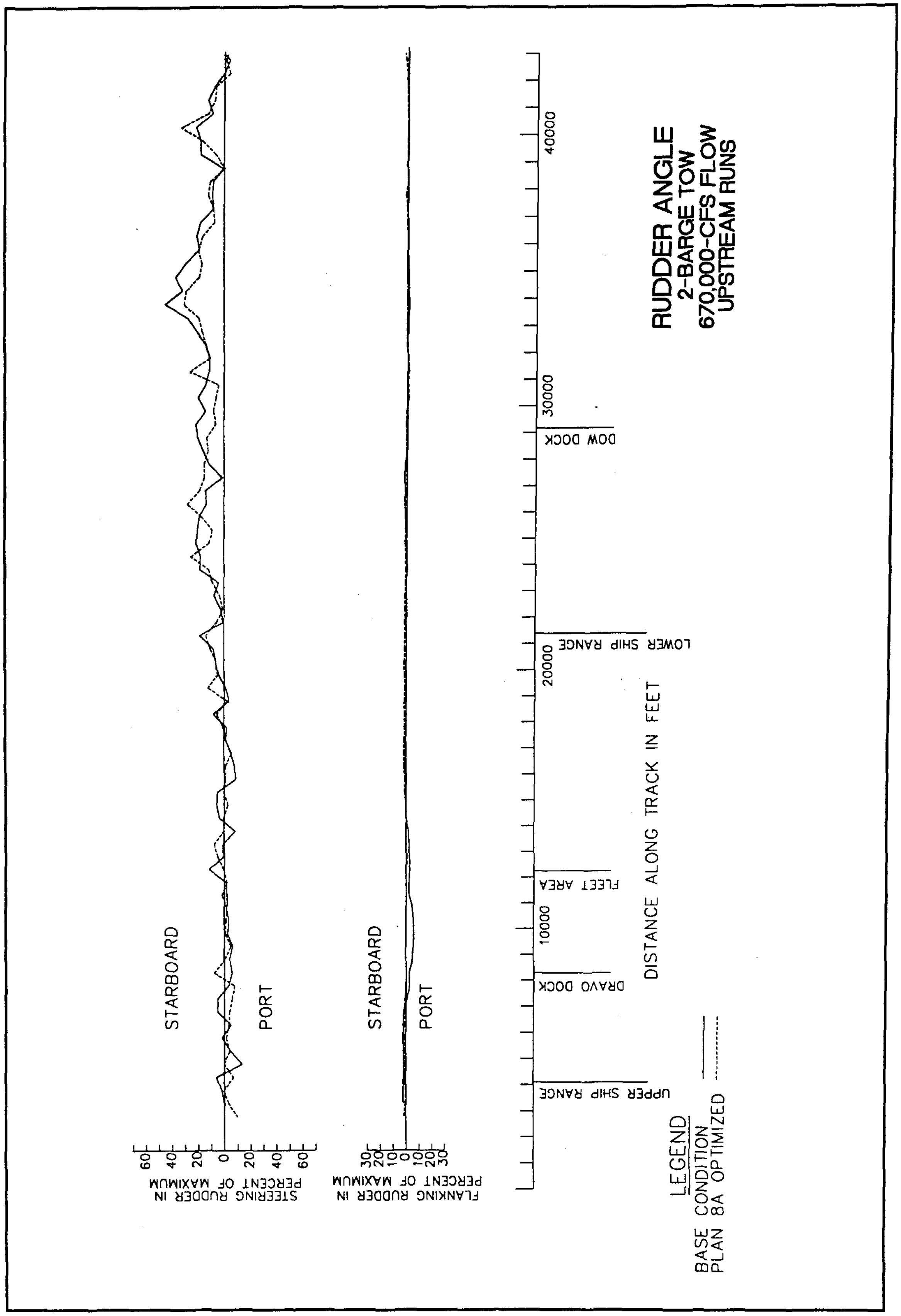

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 5A OPTIMIZED, DOWNSTREAM RUN
2-BARGE TOW, 590' LONG X 54' WIDE
1,500,000-CFS FLOW
ALL RUNS

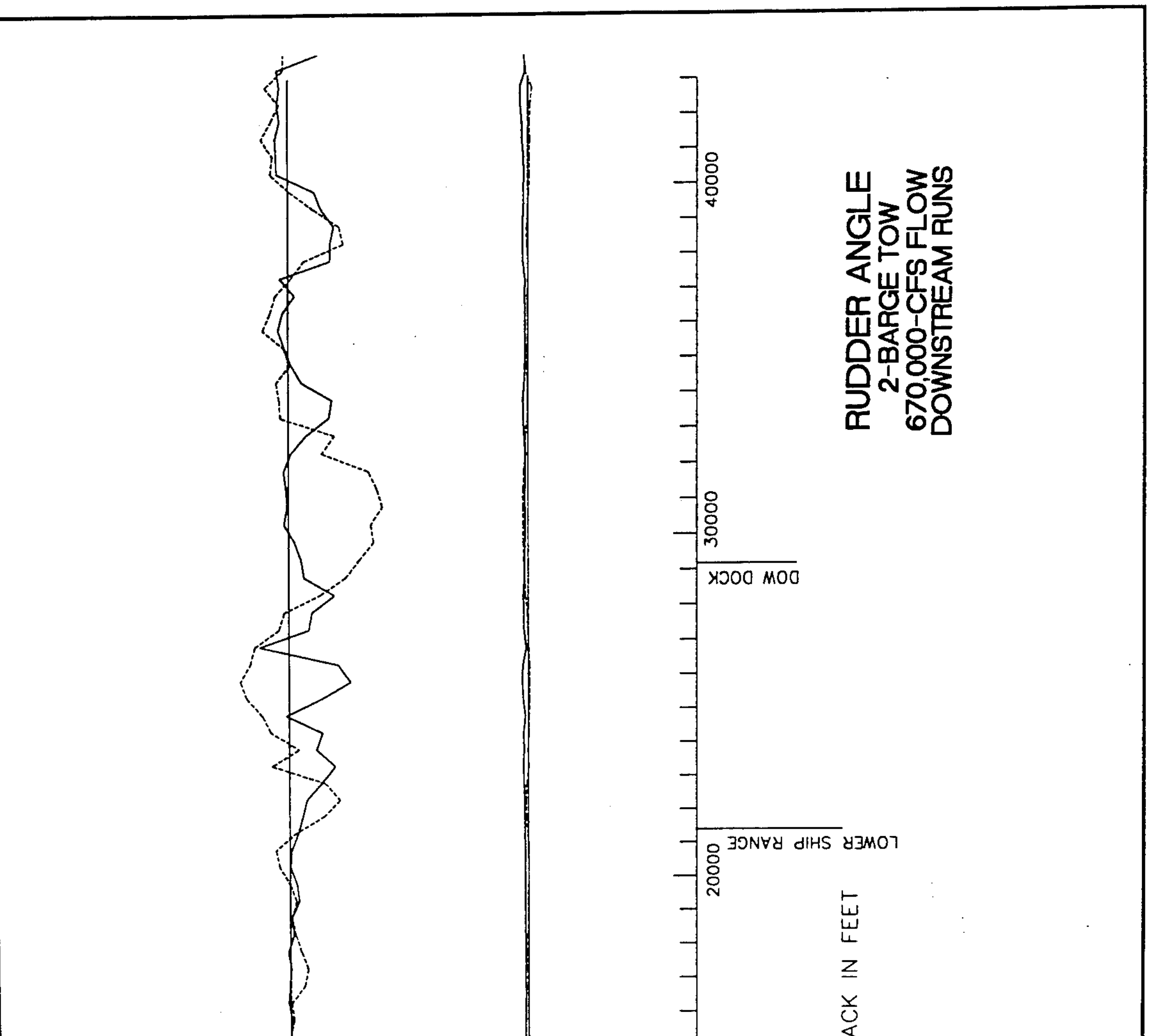

RUDDER ANGLE
2-BARGE TOW
228,000-CFS FLOW
UPSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
FLANKING RUDDER IN PERCENT OF MAXIMUM
STARBOARD
PORT
STARBOARD
PORT
60
40
20
0
20
40
60
30
20
10
0
10
20
30
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

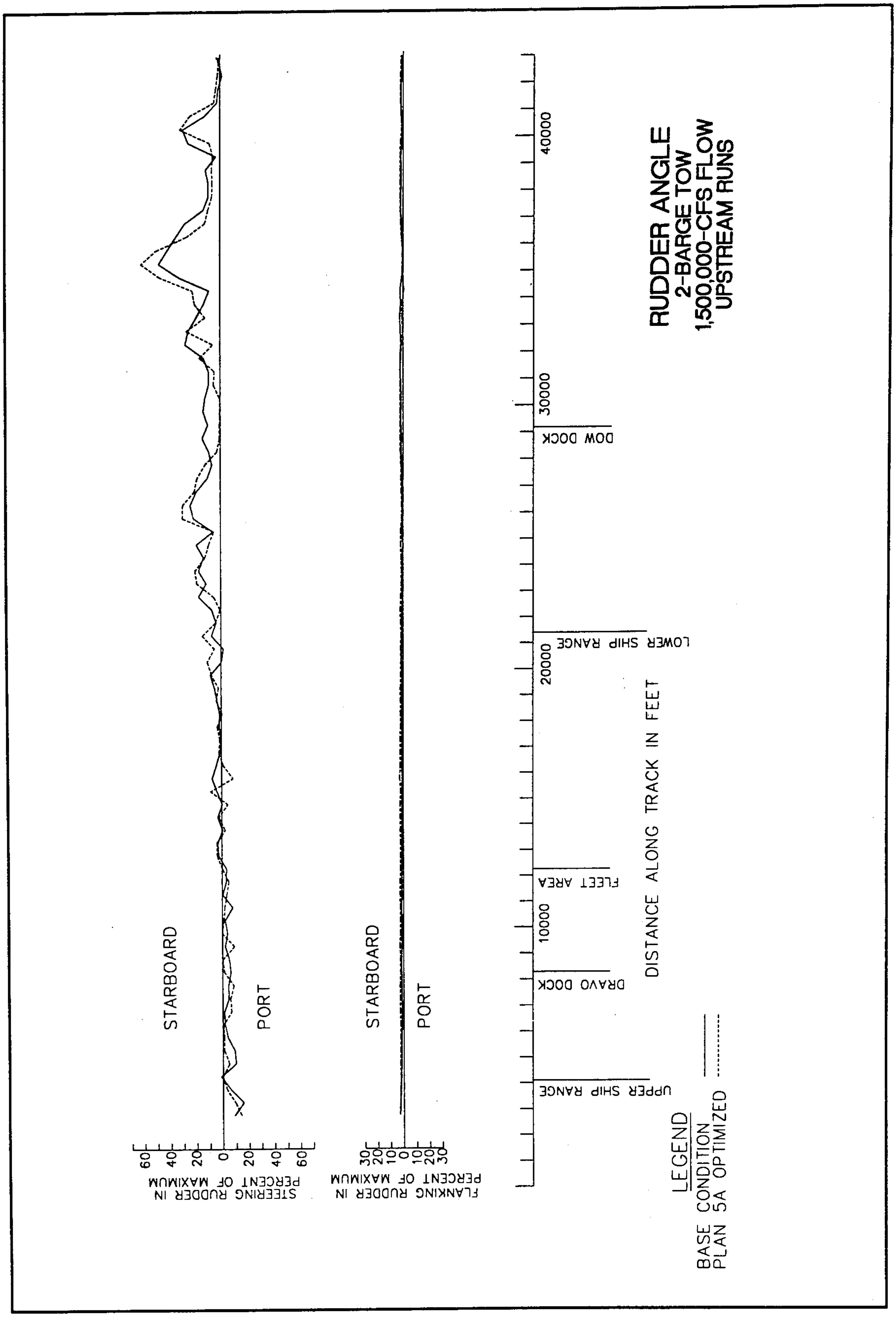

RUDDER ANGLE
2-BARGE TOW
228,000-CFS FLOW
DOWNSTREAM RUNS
STARBOARD
PORT
STARBOARD
PORT
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED


RUDDER ANGLE
2-BARGE TOW
450,000-CFS FLOW
UPSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
FLANKING RUDDER IN PERCENT OF MAXIMUM
STARBOARD
PORT
STARBOARD
PORT
60
40
20
0
20
40
60
30
20
10
0
10
20
30
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
30000
DOW DOCK
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED


RUDDER ANGLE
2-BARGE TOW
450,000-CFS FLOW
DOWNSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED


RUDDER ANGLE
2-BARGE TOW
670,000-CFS FLOW
UPSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
30000
DOW DOCK
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


RUDDER ANGLE
2-BARGE TOW
670,000-CFS FLOW
DOWNSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


RUDDER ANGLE
2-BARGE TOW
1,500,000-CFS FLOW
UPSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
10000
20000
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

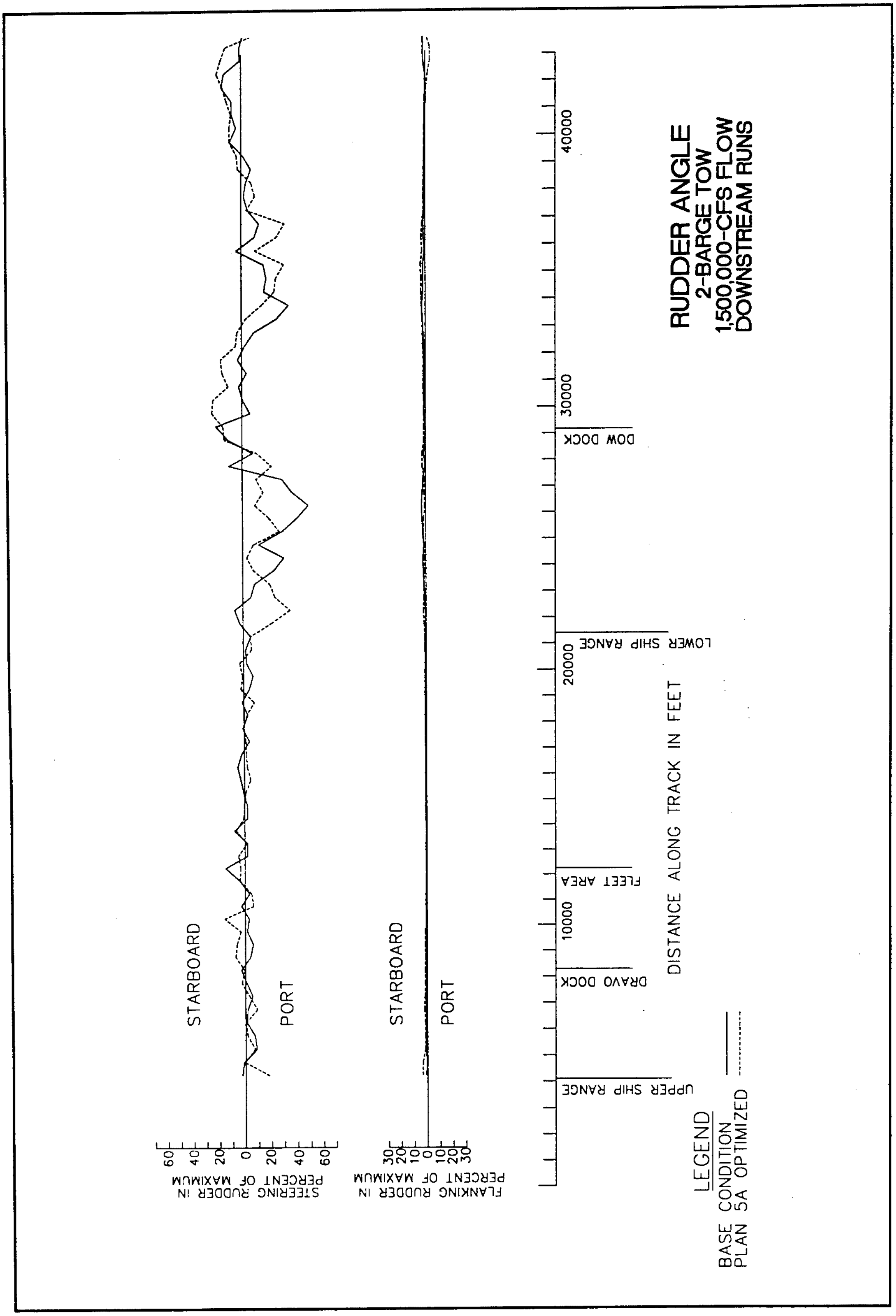
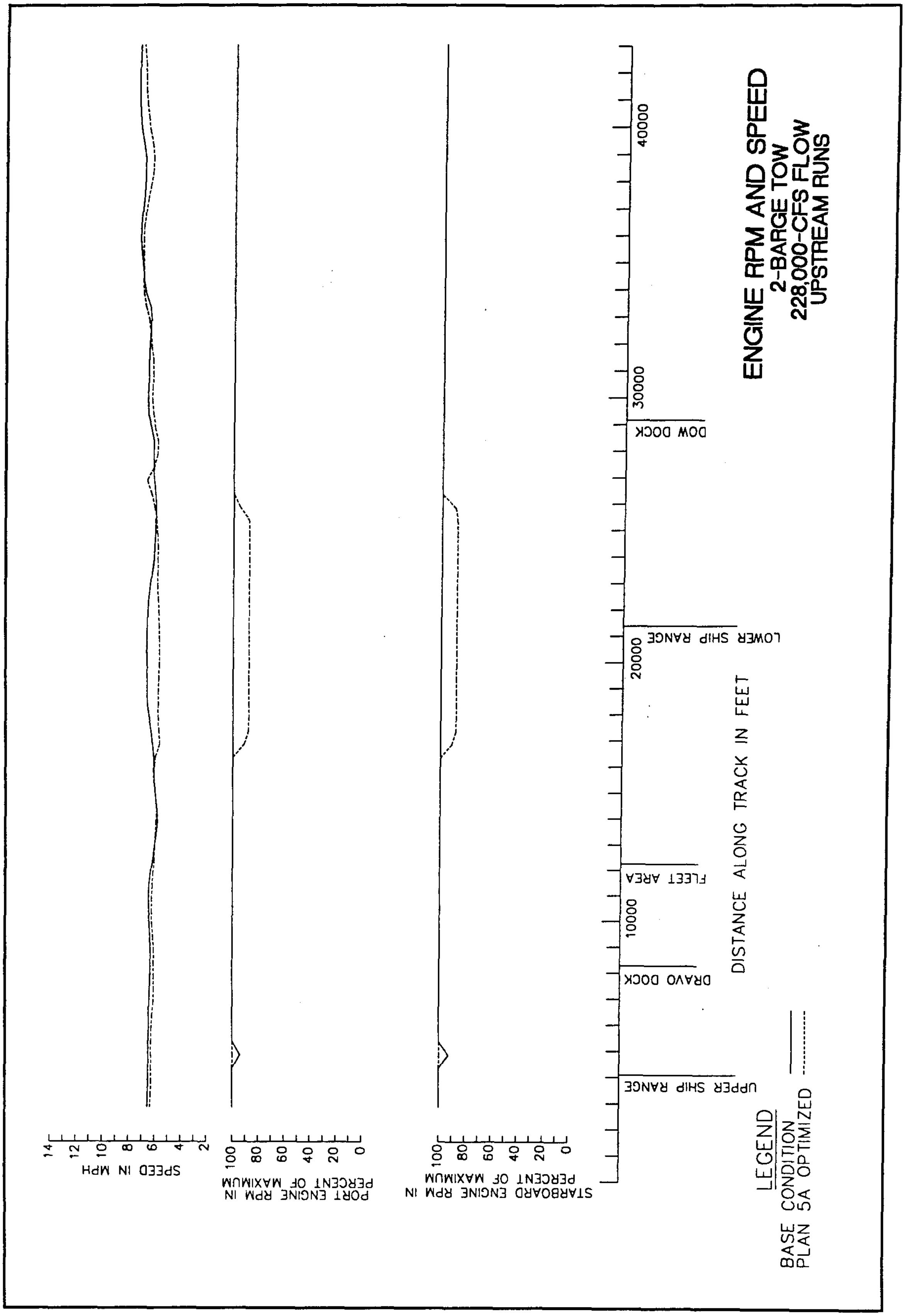
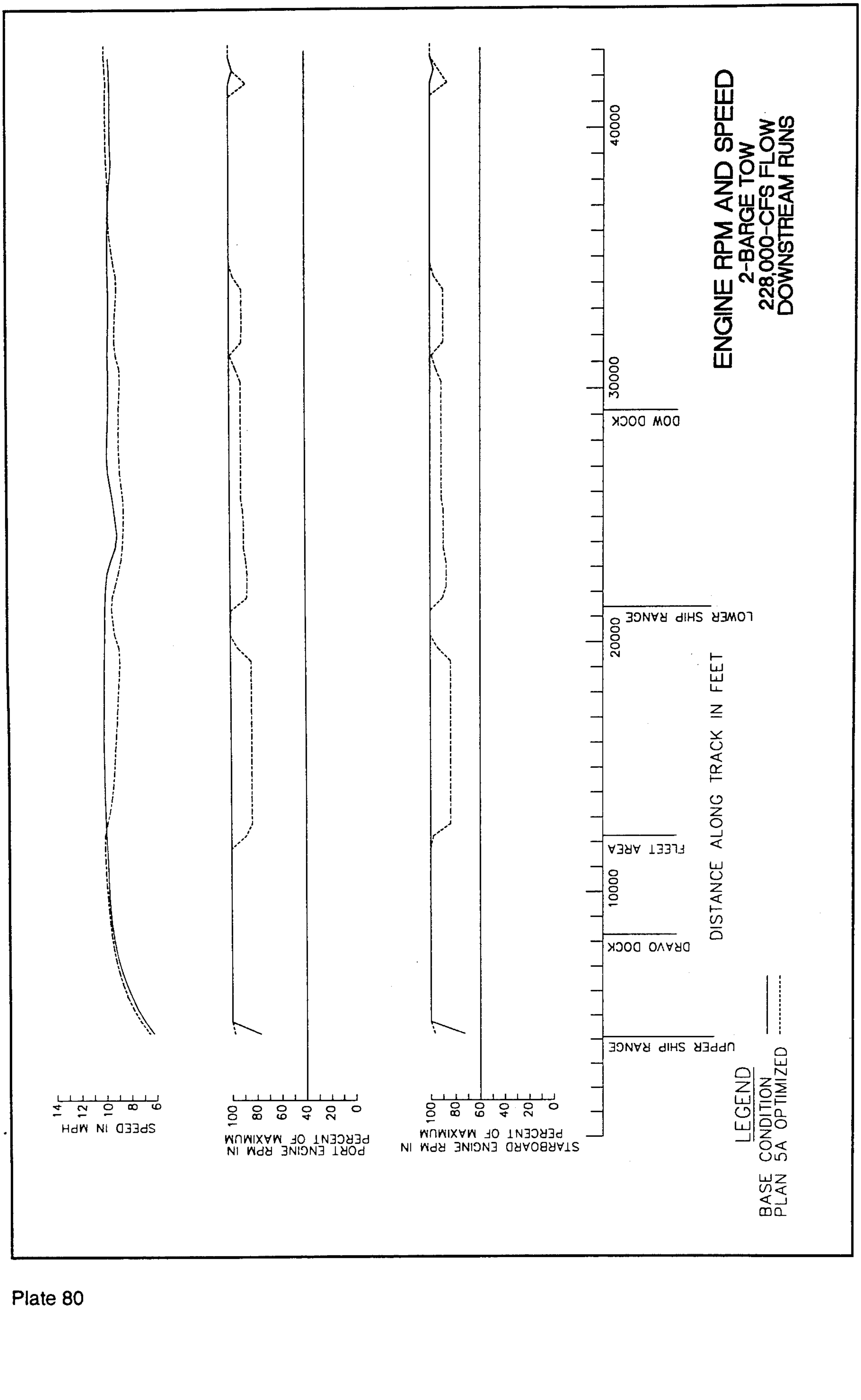
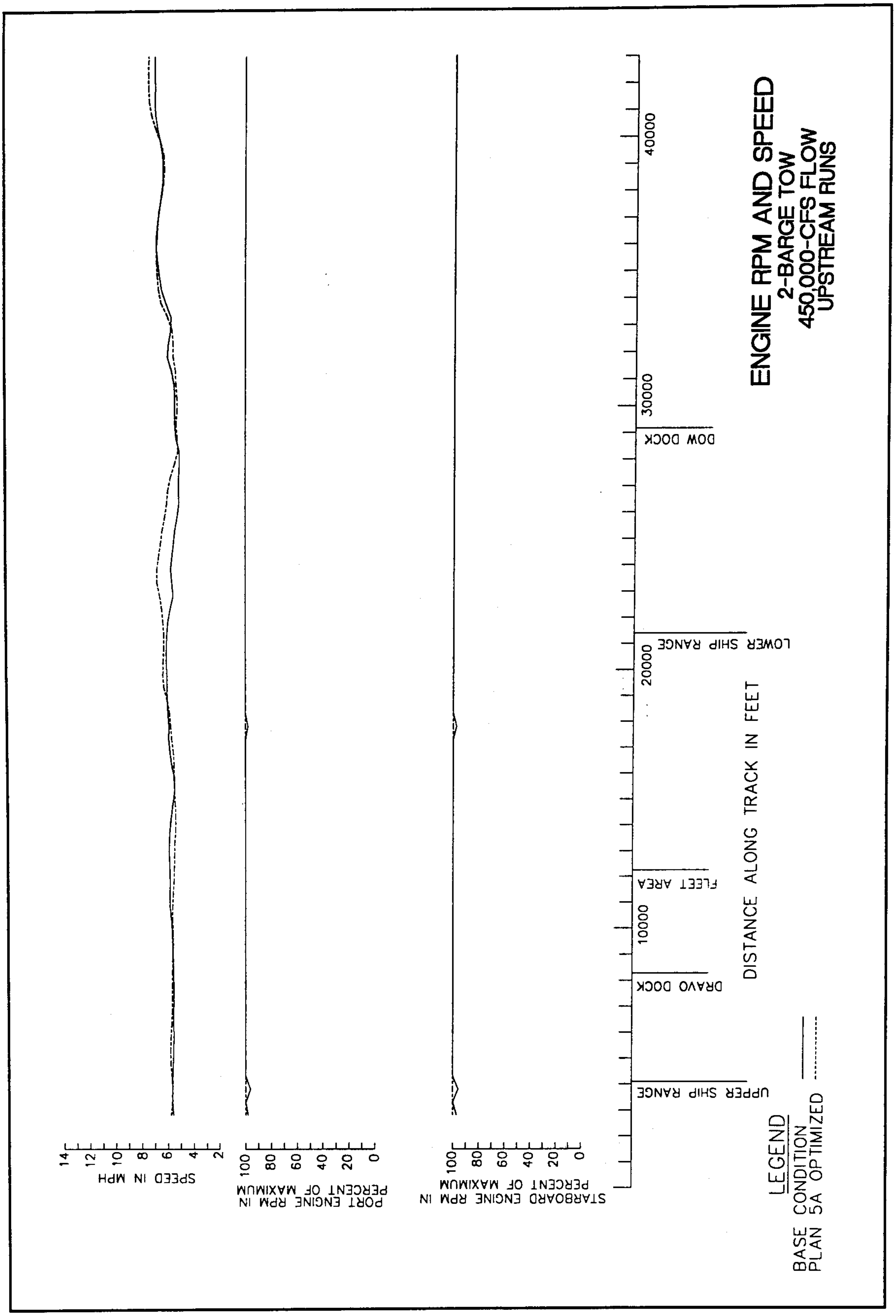
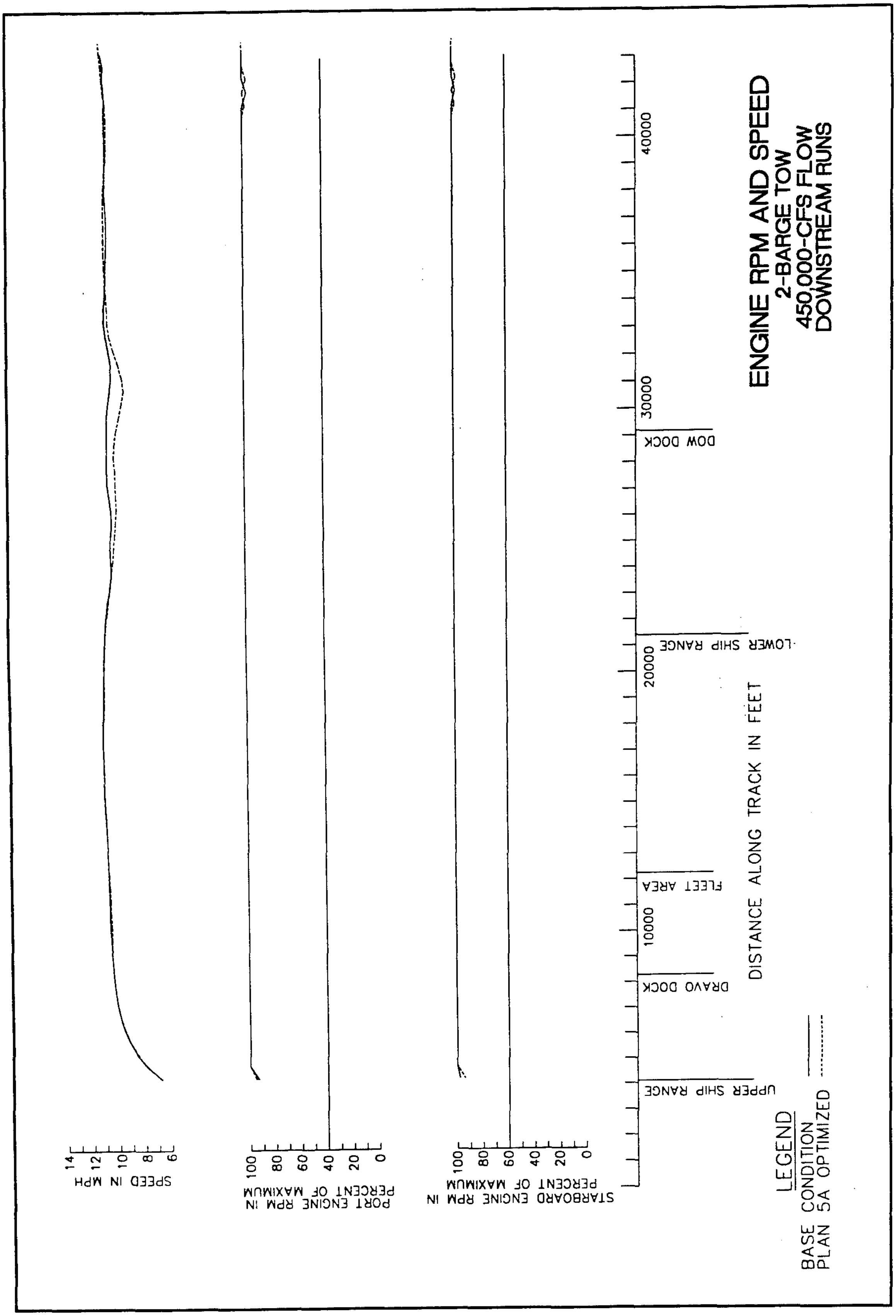

RUDDER ANGLE
2-BARGE TOW
1,500,000-CFS FLOW
DOWNSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

Plate 78

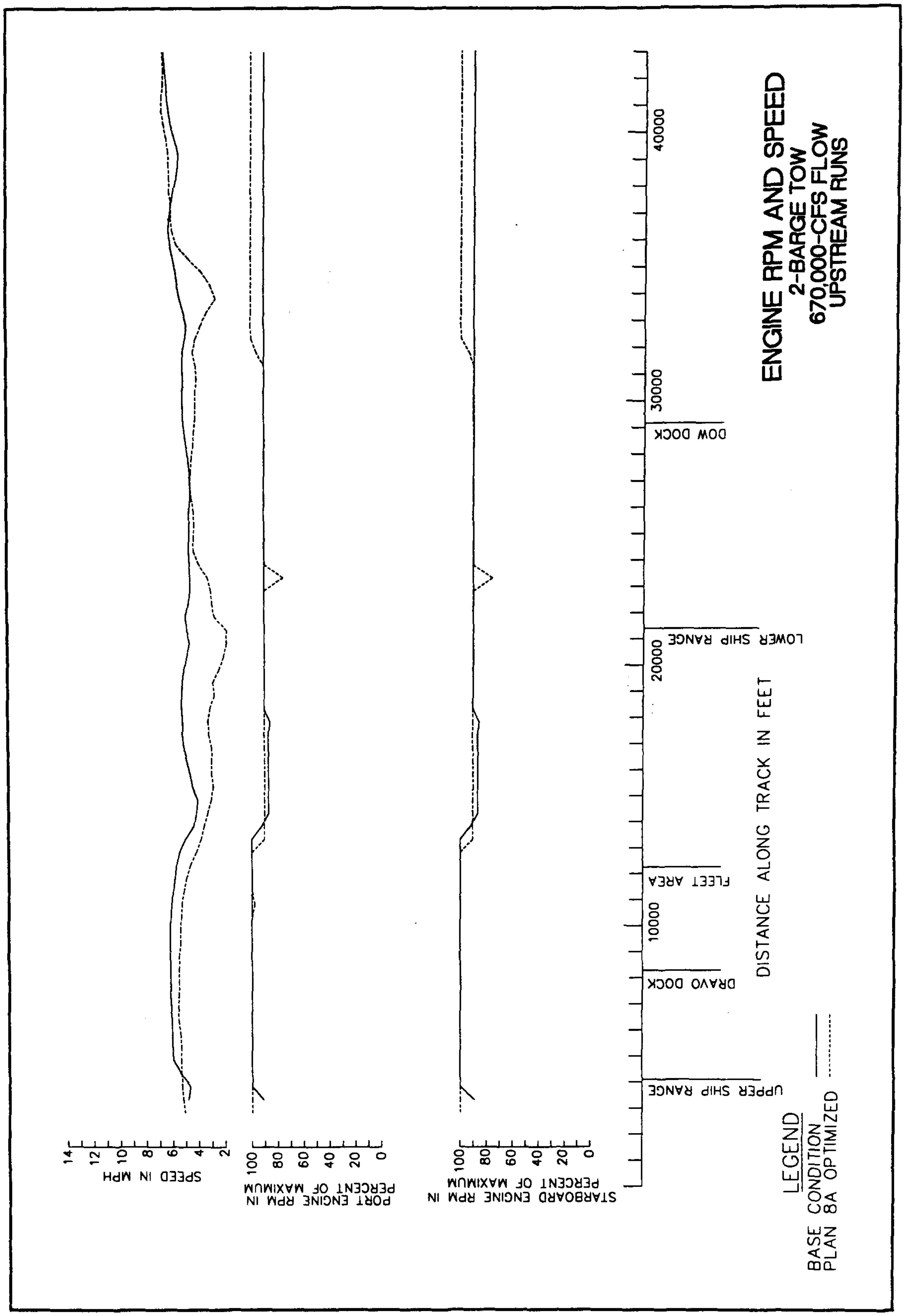

ENGINE RPM AND SPEED
2-BARGE TOW
228,000-CFS FLOW
UPSTREAM RUNS
SPEED IN MPH
PORT ENGINE RPM IN PERCENT OF MAXIMUM
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
DISTANCE ALONG TRACK IN FEET
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
10000
20000
30000
40000
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED


ENGINE RPM AND SPEED
2-BARGE TOW
228,000-CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
PORT ENGINE RPM IN PERCENT OF MAXIMUM
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
DISTANCE ALONG TRACK IN FEET
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
10000
20000
30000
40000
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

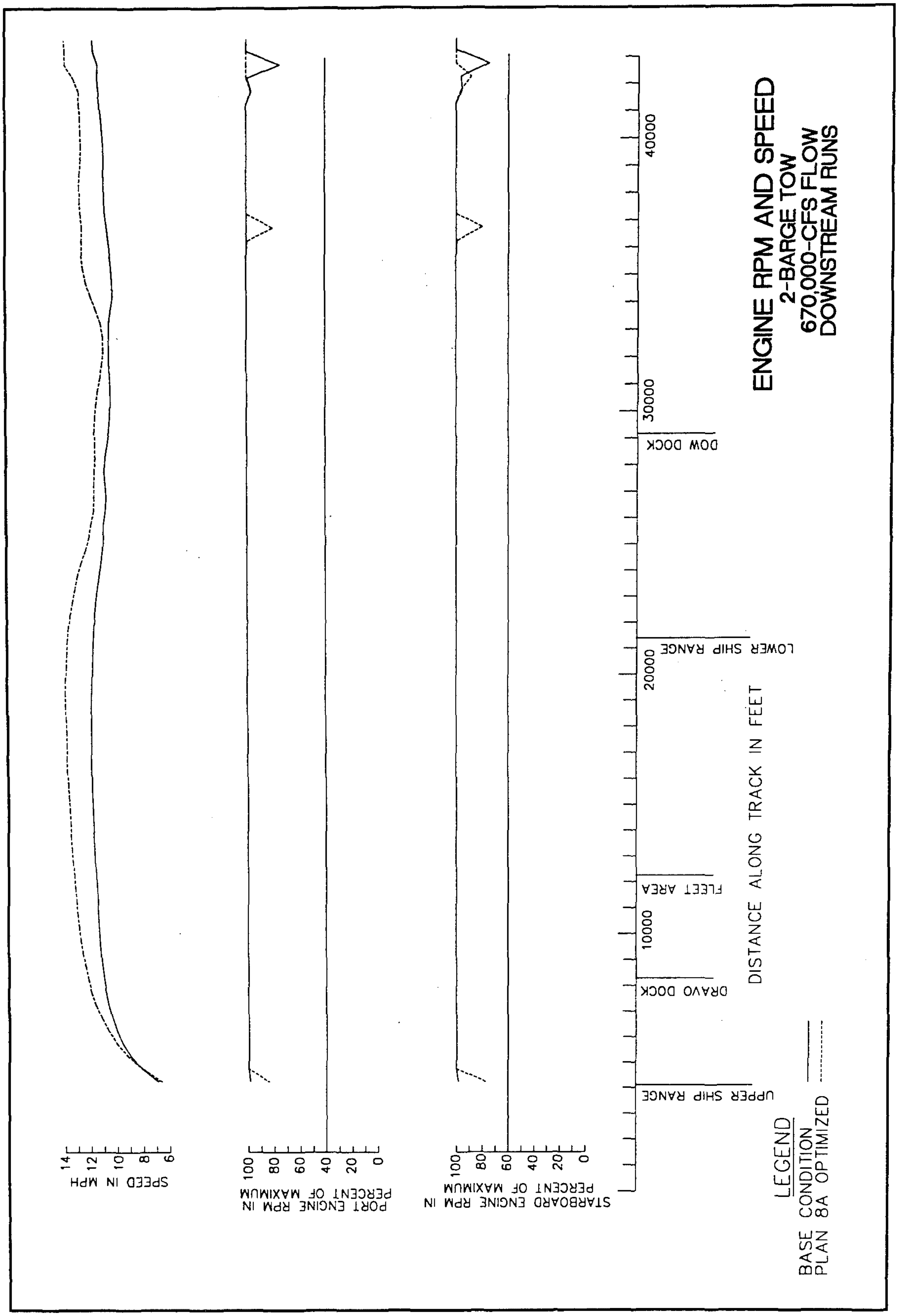

ENGINE RPM AND SPEED
2-BARGE TOW
450,000-CFS FLOW
UPSTREAM RUNS
SPEED IN MPH
14
12
10
8
6
4
2
PORT ENGINE RPM IN PERCENT OF MAXIMUM
100
80
60
40
20
0
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
100
80
60
40
20
0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

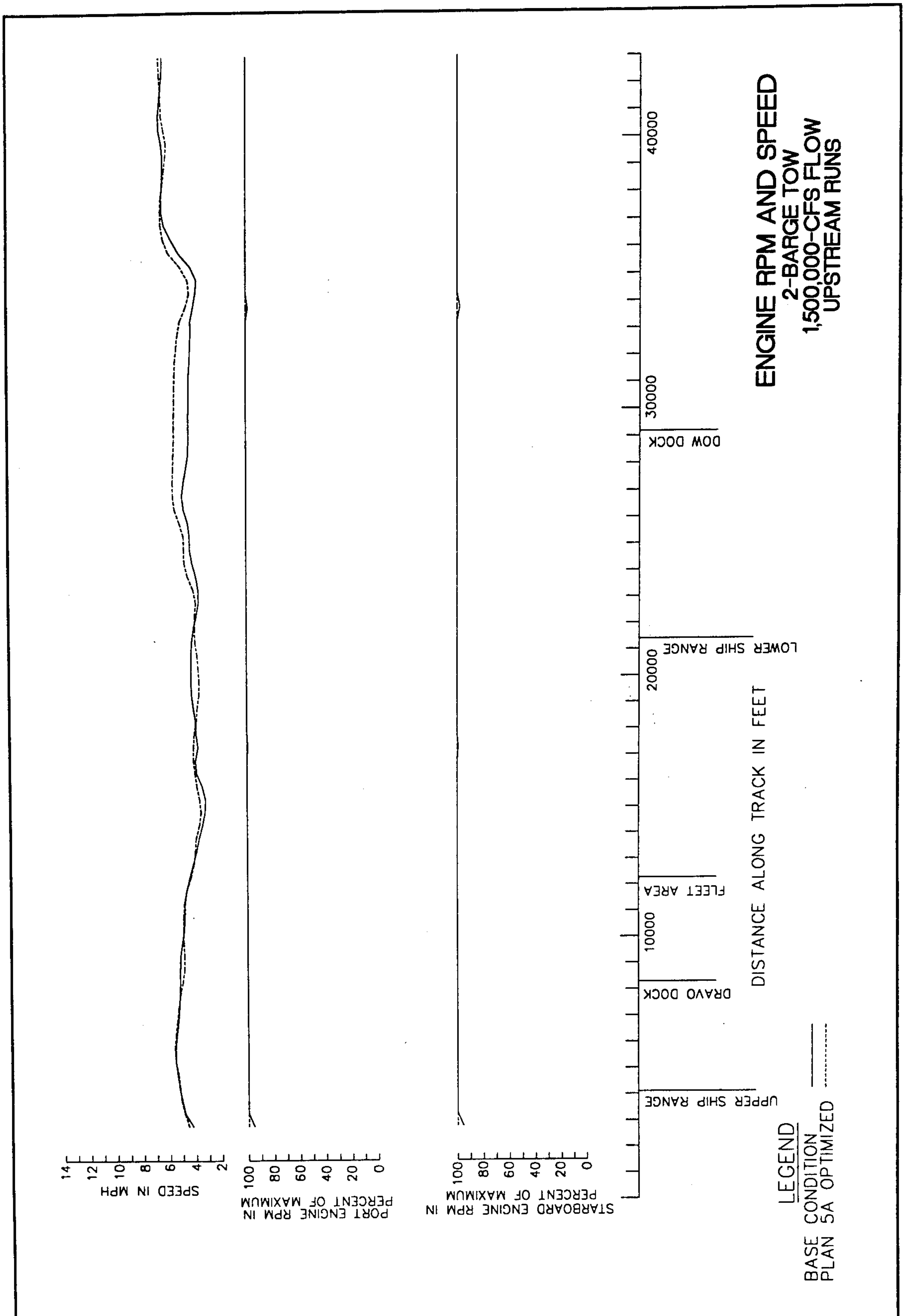


ENGINE RPM AND SPEED
2-BARGE TOW
450,000-CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
14 12 10 8 6
PORT ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED



ENGINE RPM AND SPEED
2-BARGE TOW
670,000-CFS FLOW
UPSTREAM RUNS
SPEED IN MPH
14
12
10
8
6
4
2
PORT ENGINE RPM IN PERCENT OF MAXIMUM
100
80
60
40
20
0
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
100
80
60
40
20
0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


ENGINE RPM AND SPEED
2-BARGE TOW
670,000-CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
14 12 10 8 6
PORT ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
10000
20000
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


ENGINE RPM AND SPEED
2-BARGE TOW
1,500,000-CFS FLOW
UPSTREAM RUNS
SPEED IN MPH
14 12 10 8 6 4 2
PORT ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

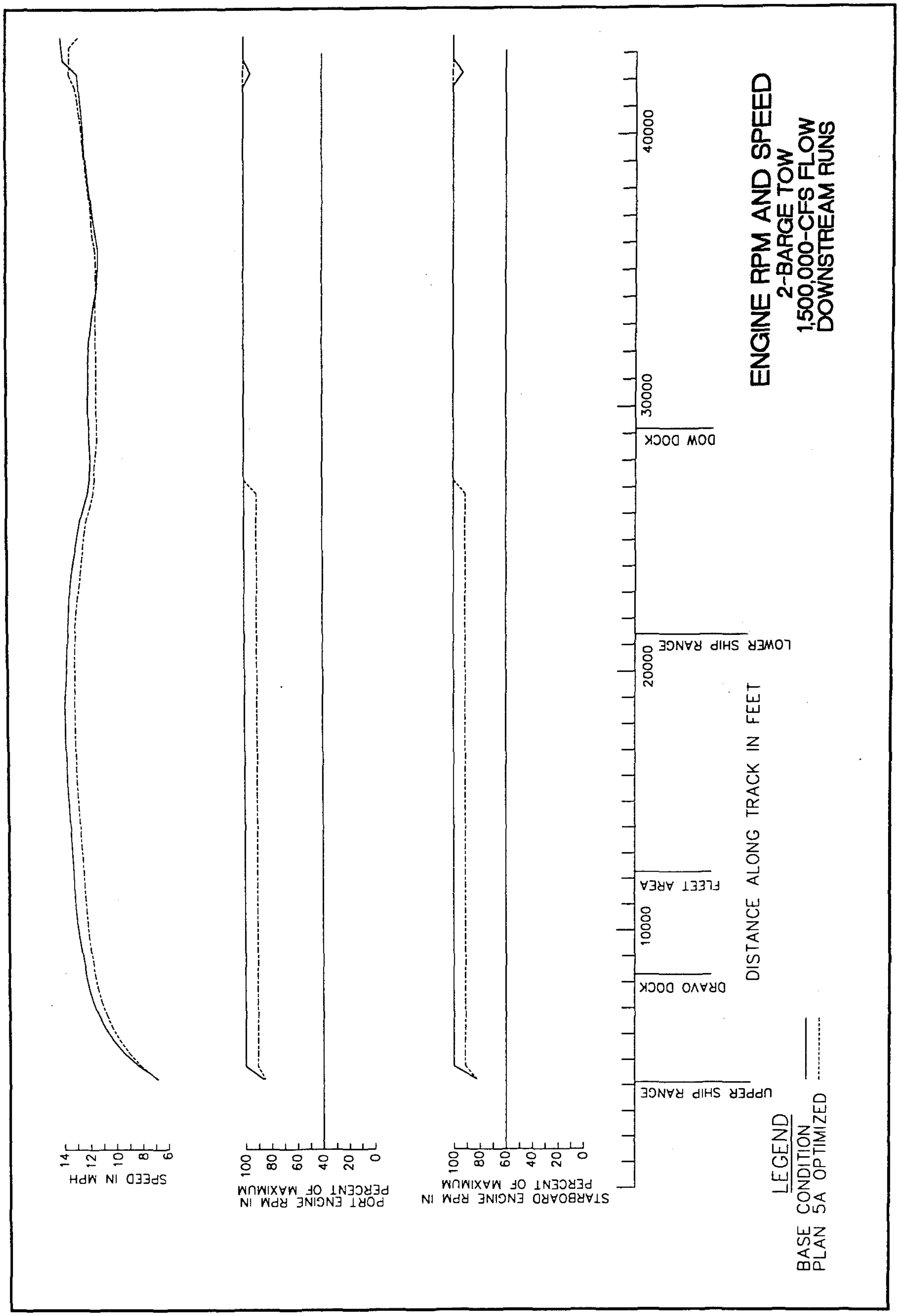
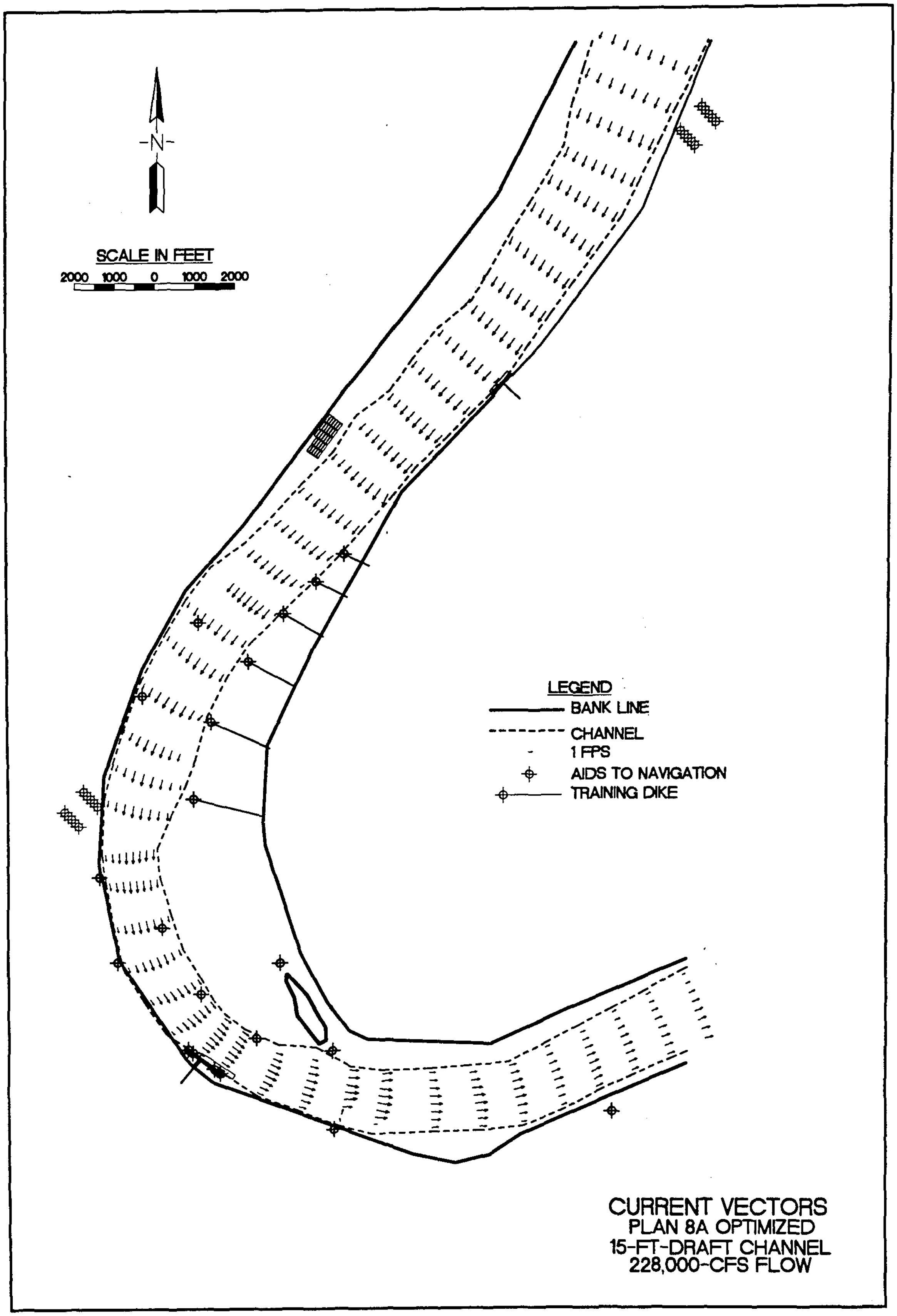
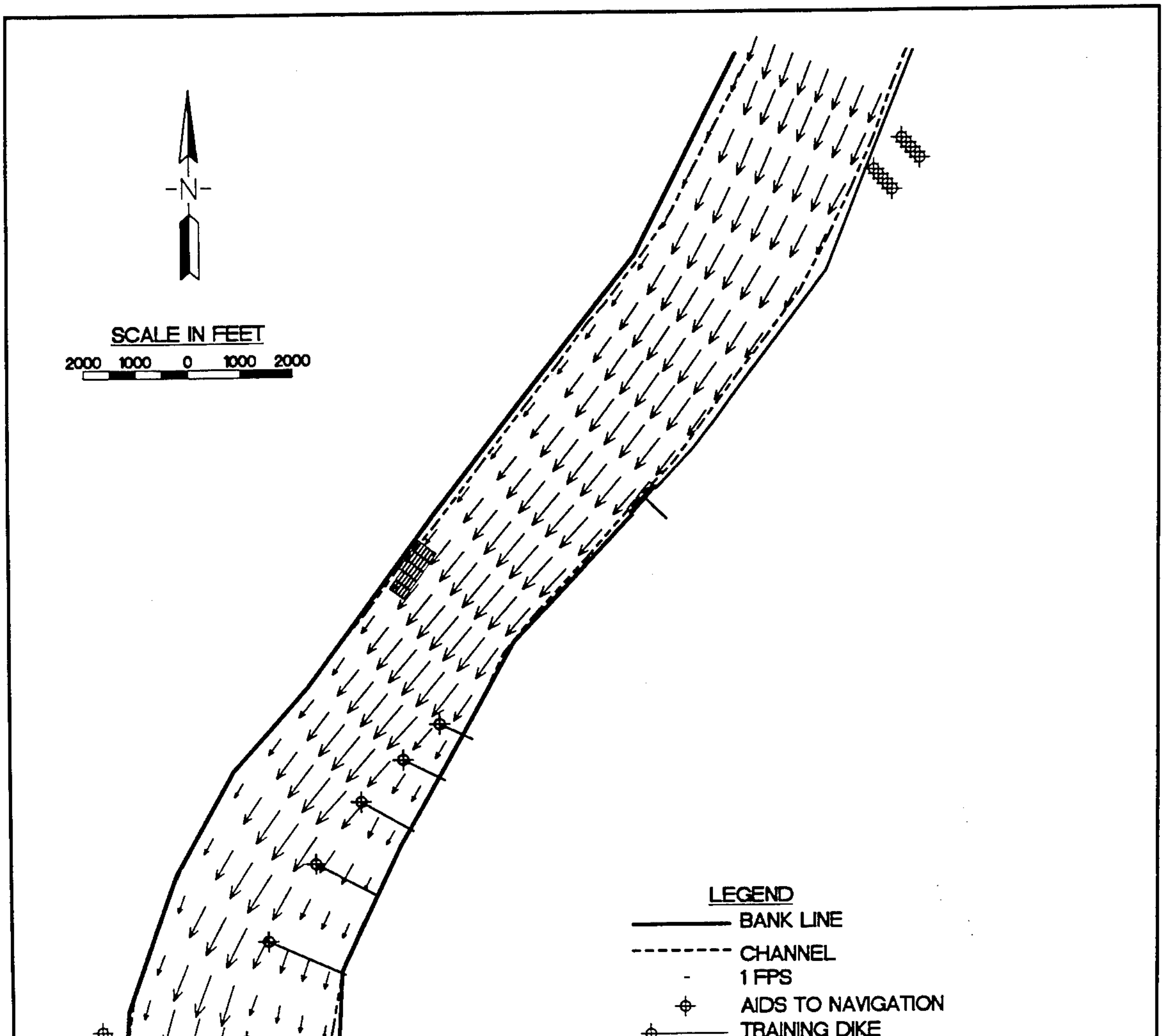
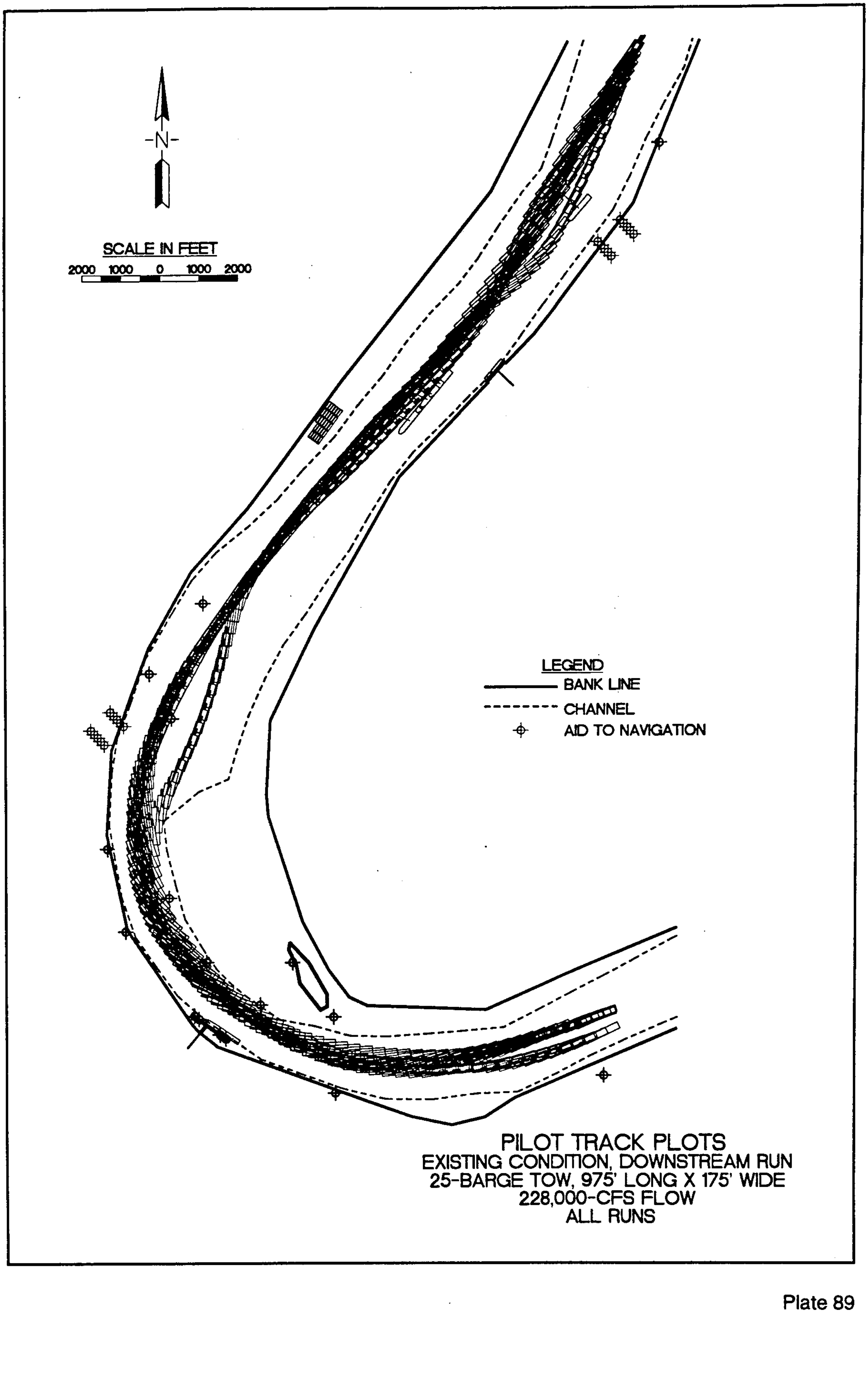
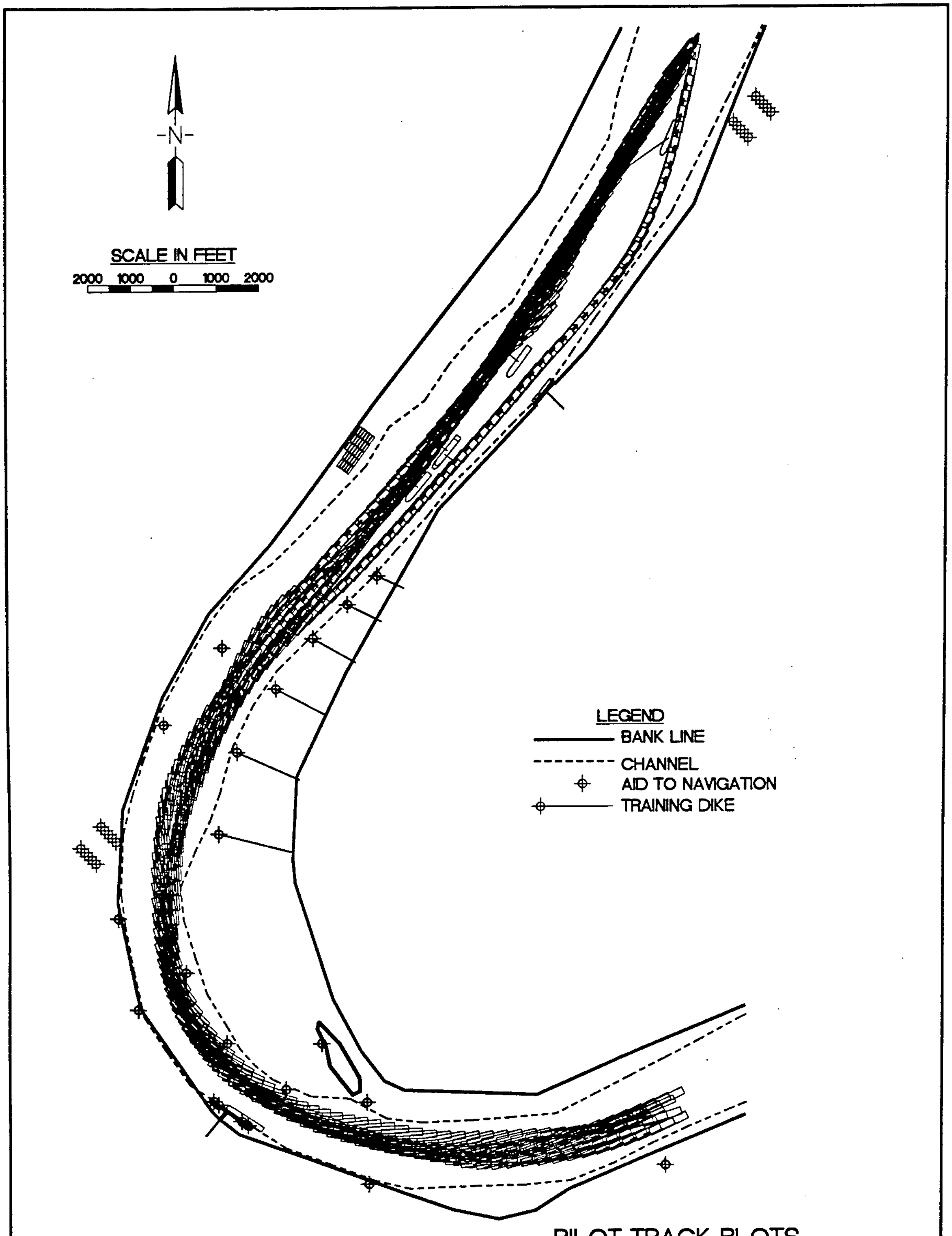

ENGINE RPM AND SPEED
2-BARGE TOW
1,500,000-CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
14 12 10 8 6
PORT ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 5A OPTIMIZED

Plate 86

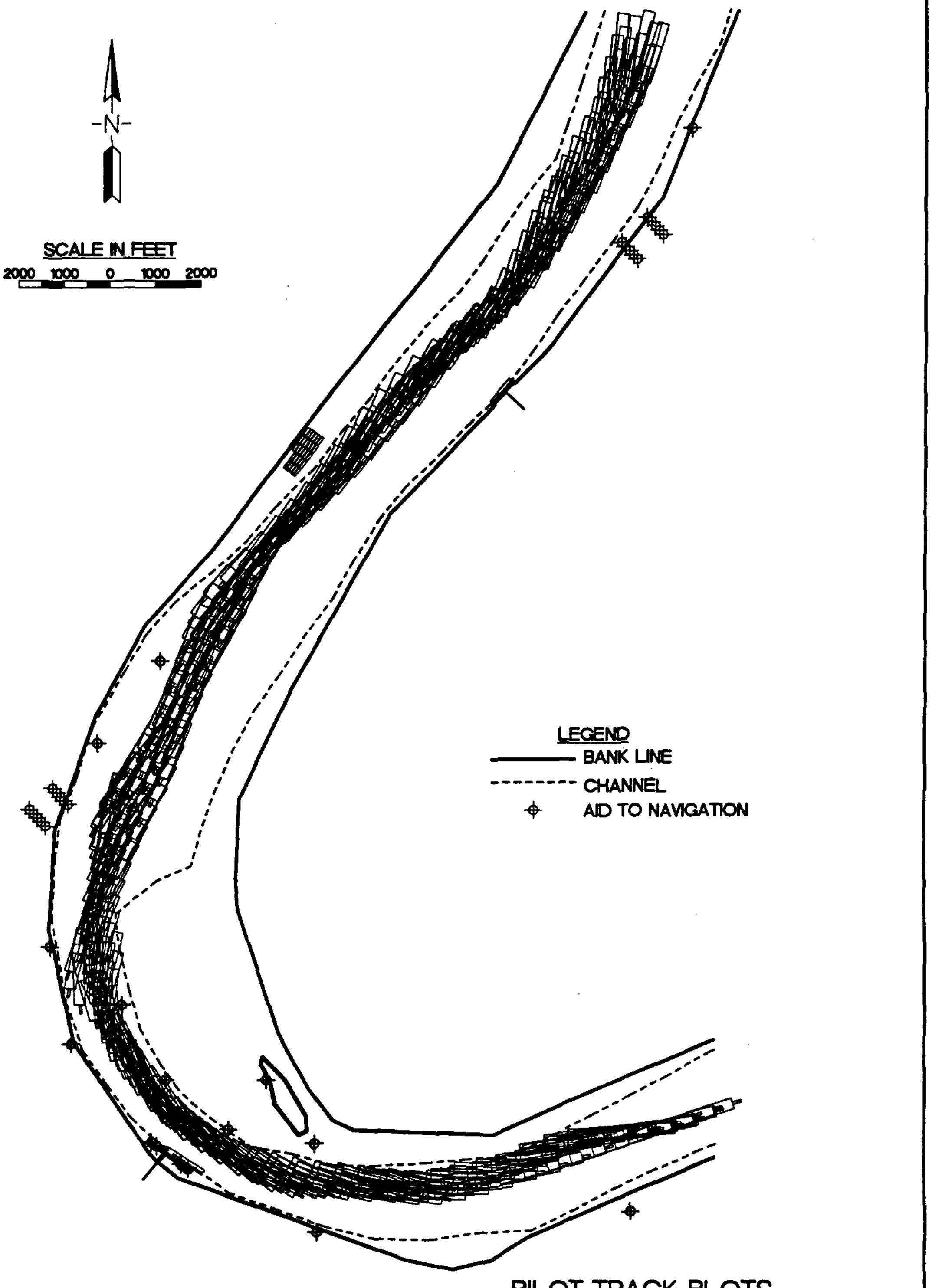

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 8A OPTIMIZED
15-FT-DRAFT CHANNEL
228,000-CFS FLOW


-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
1 FPS
AIDS TO NAVIGATION
TRAINING DIKE
CURRENT VECTORS
PLAN 8A OPTIMIZED
15-FT-DRAFT CHANNEL
1,500,000-CFS FLOW

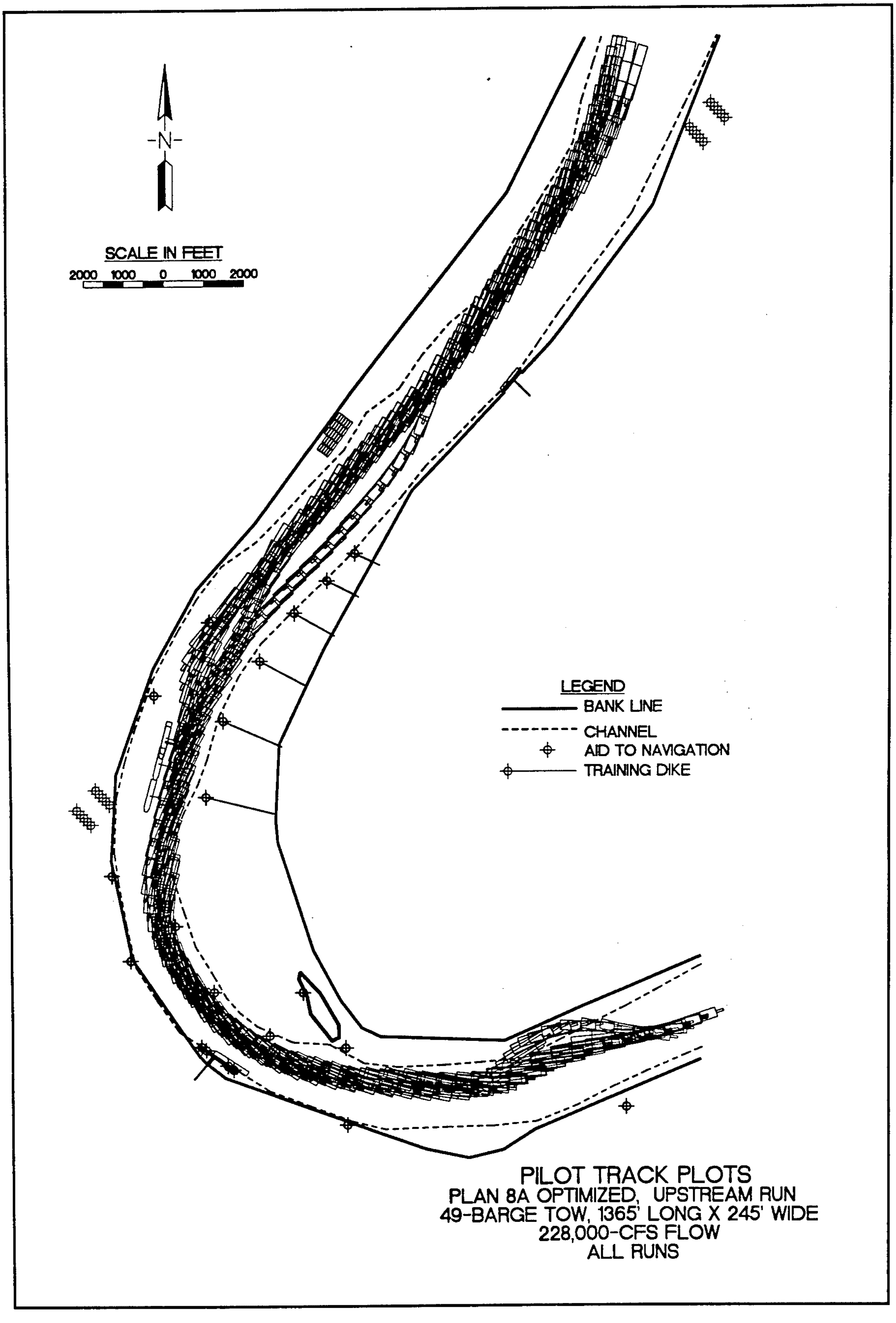

N
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
25-BARGE TOW, 975' LONG X 175' WIDE
228,000-CFS FLOW
ALL RUNS

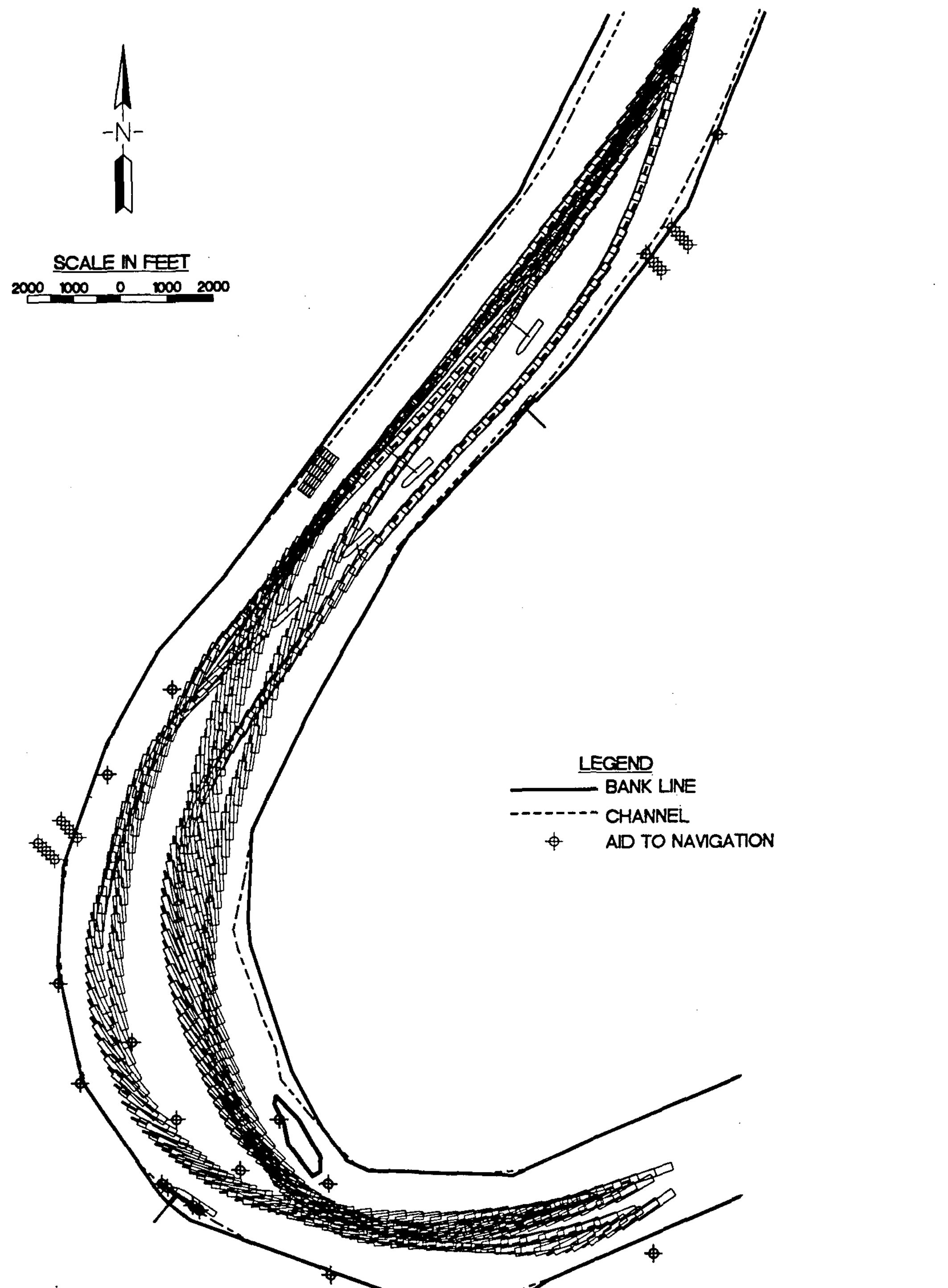



PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, DOWNSTREAM RUN
25-BARGE TOW, 975' LONG X 175' WIDE
228,000-CFS FLOW
ALL RUNS

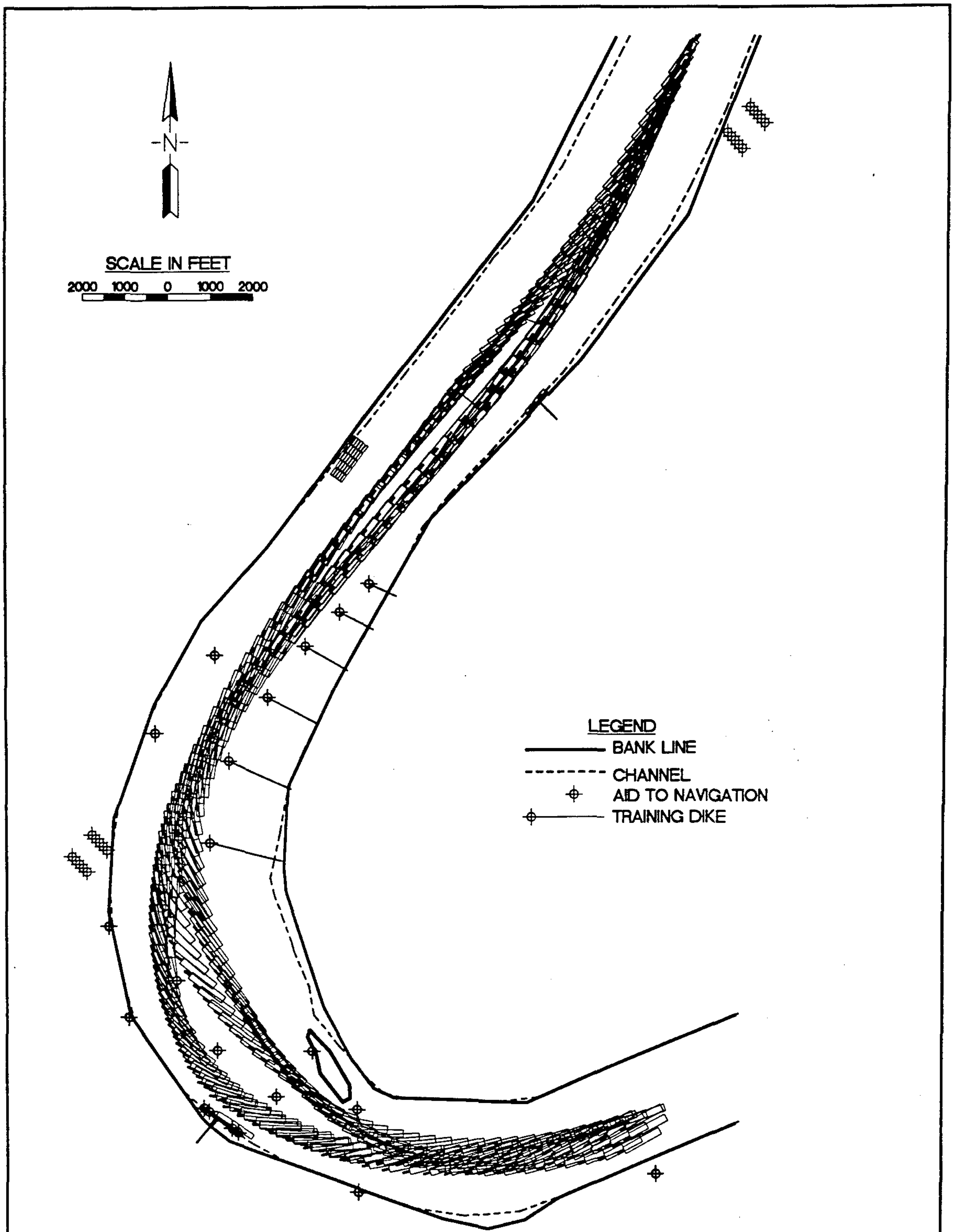



PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
49-BARGE TOW, 1365' LONG X 245' WIDE
228,000-CFS FLOW
ALL RUNS

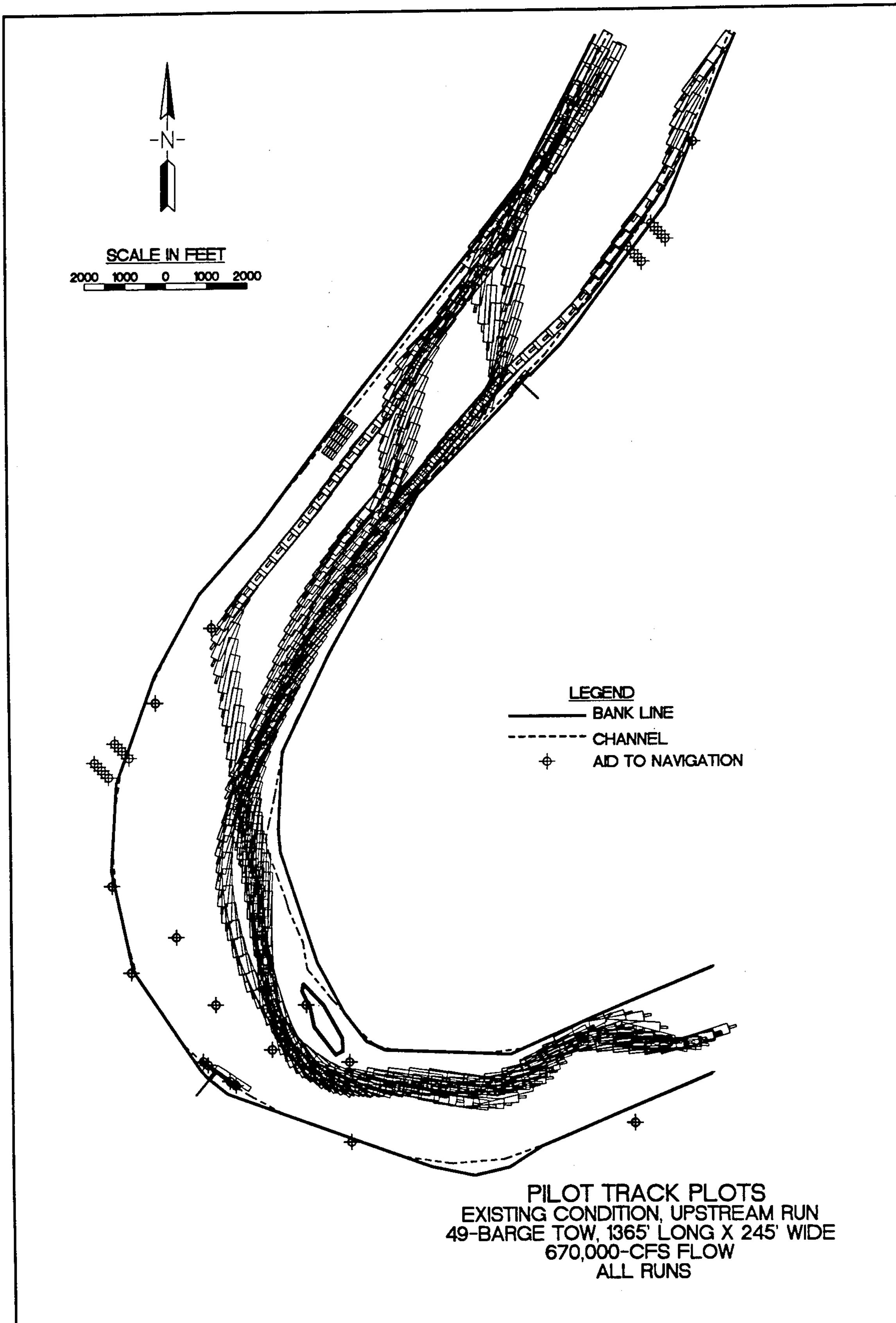

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, UPSTREAM RUN
49-BARGE TOW, 1365' LONG X 245' WIDE
228,000-CFS FLOW
ALL RUNS



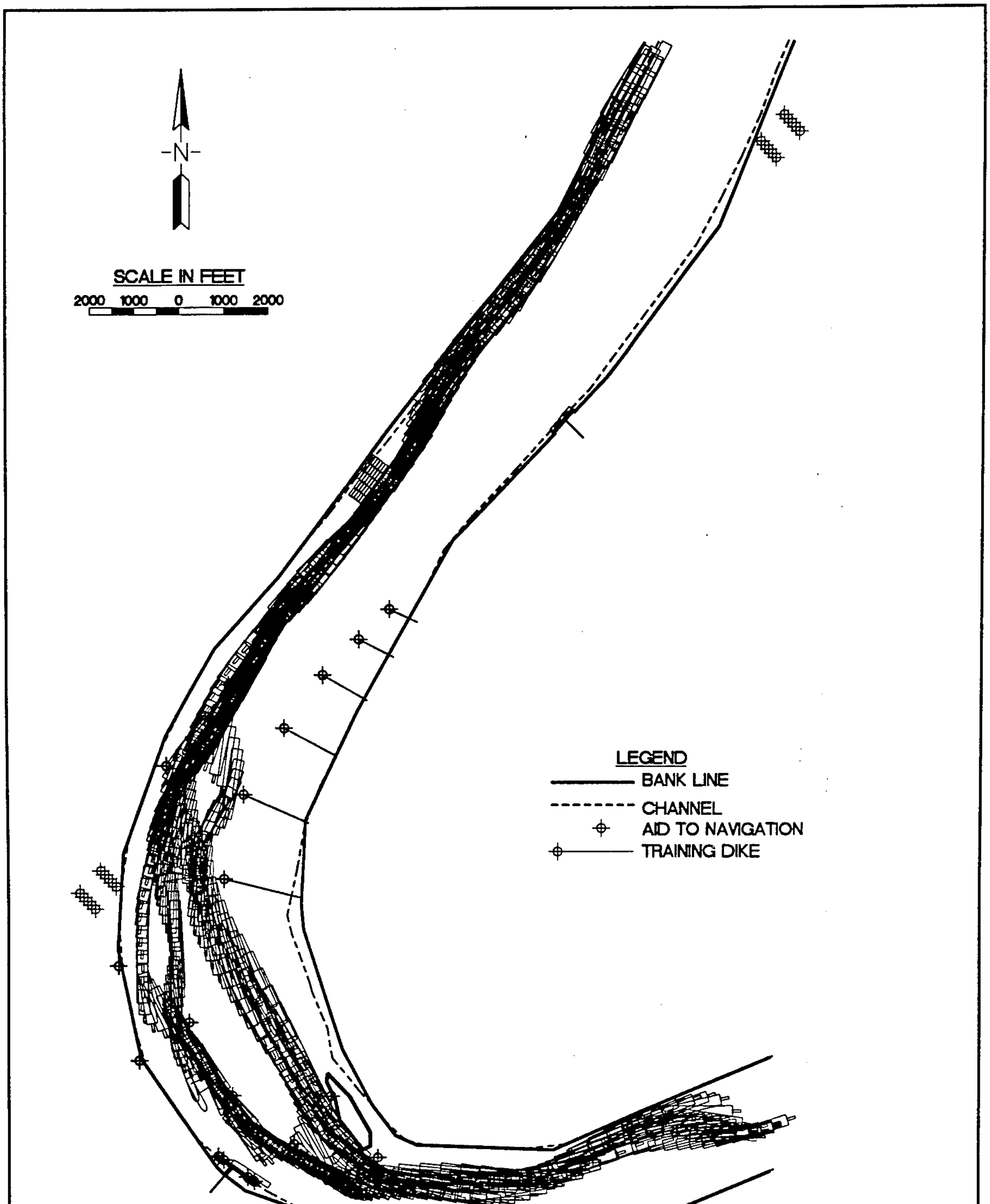

PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
25-BARGE TOW, 975' LONG X 175' WIDE
670,000-CFS FLOW
ALL RUNS



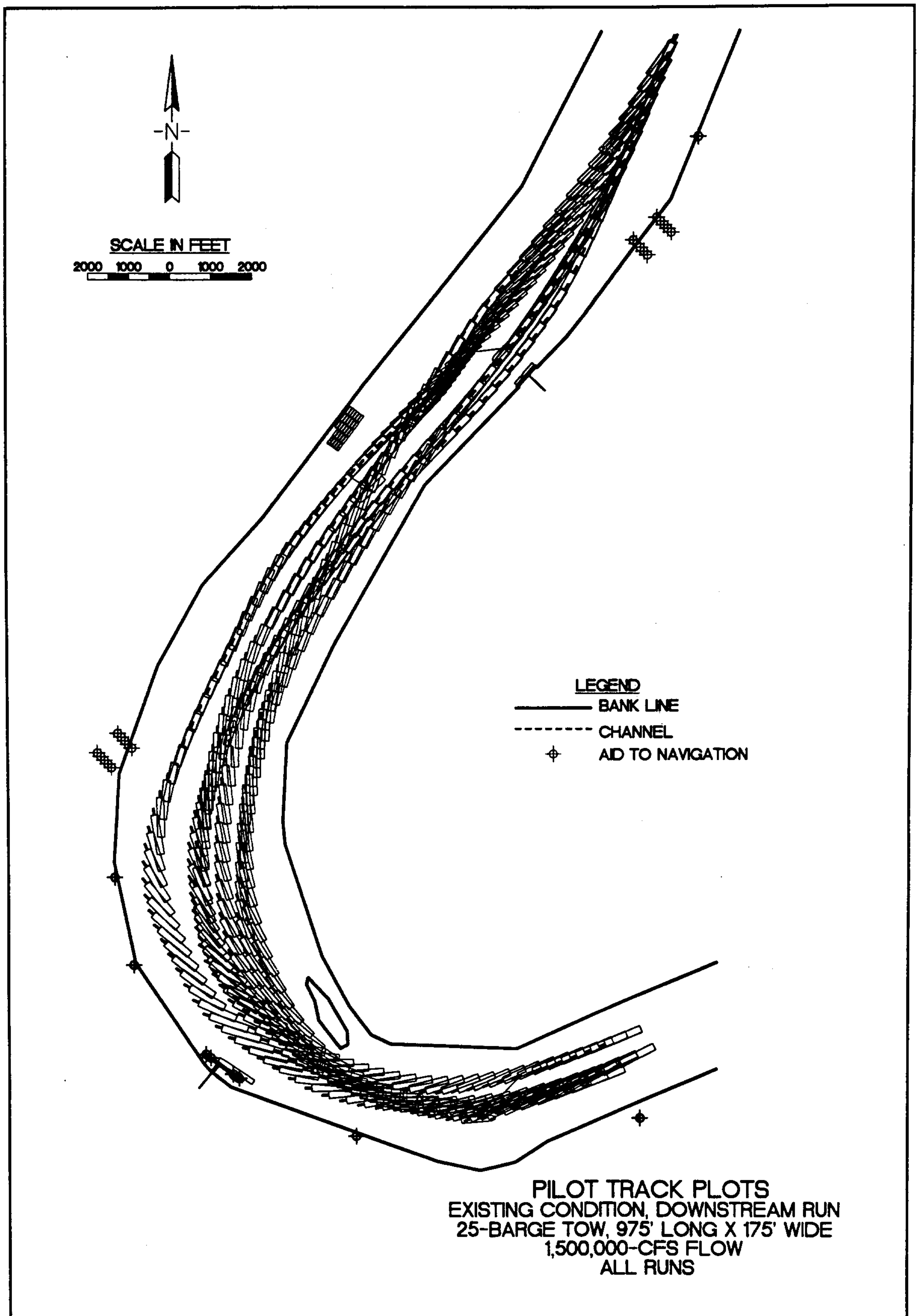

PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, DOWNSTREAM RUN
25-BARGE TOW, 975' LONG X 175' WIDE
670,000-CFS FLOW
ALL RUNS

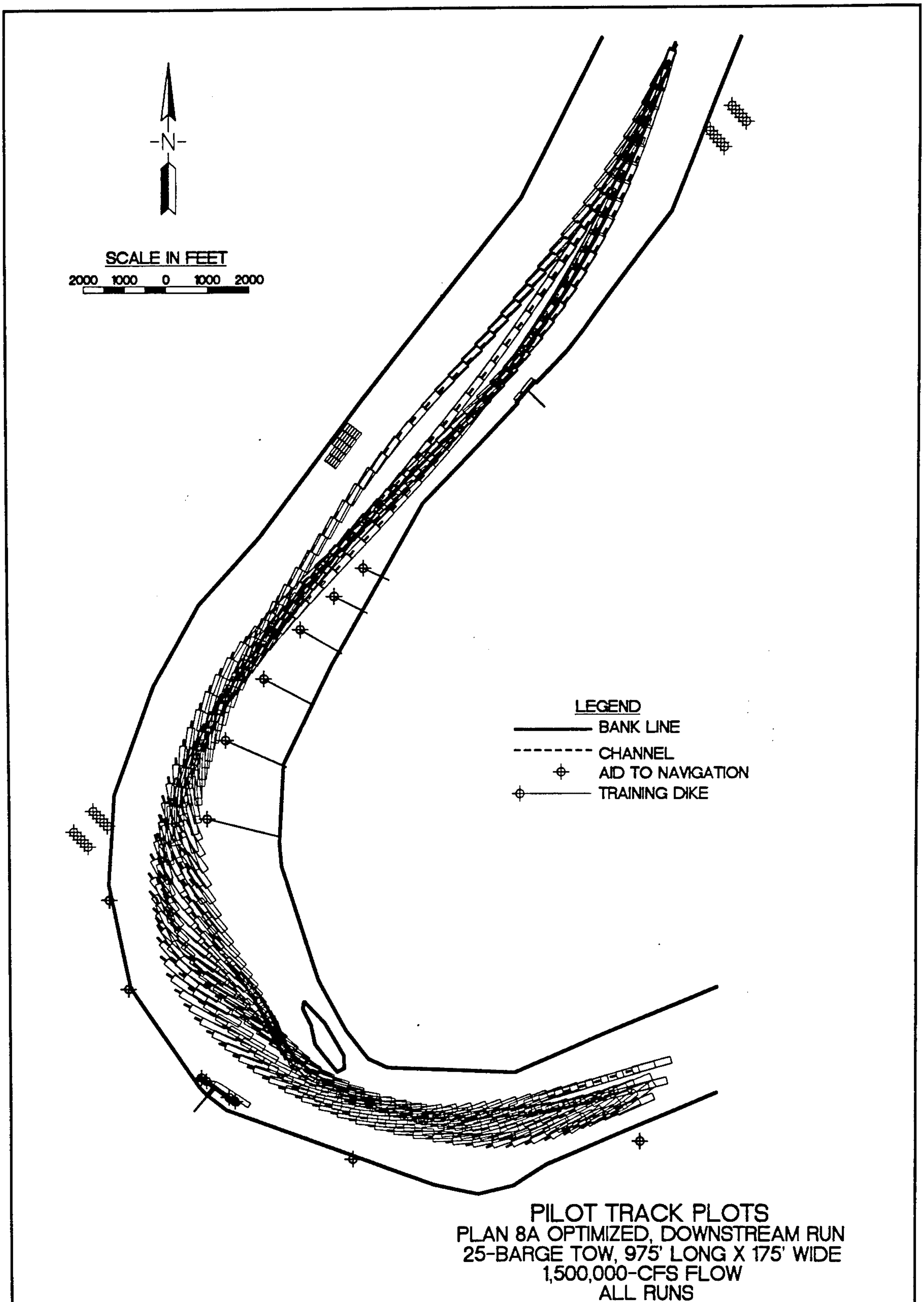


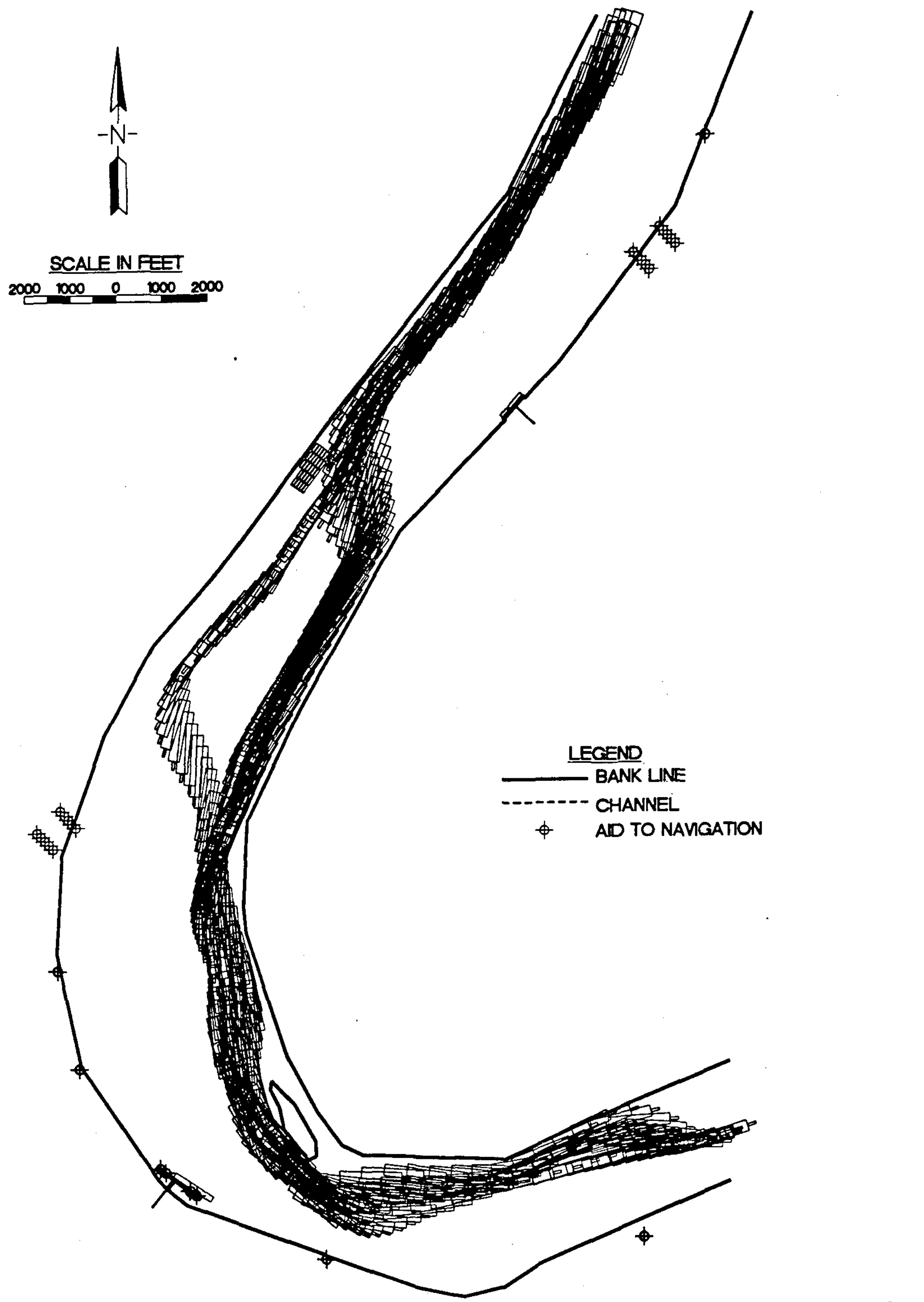
-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
49-BARGE TOW, 1365' LONG X 245' WIDE
670,000-CFS FLOW
ALL RUNS



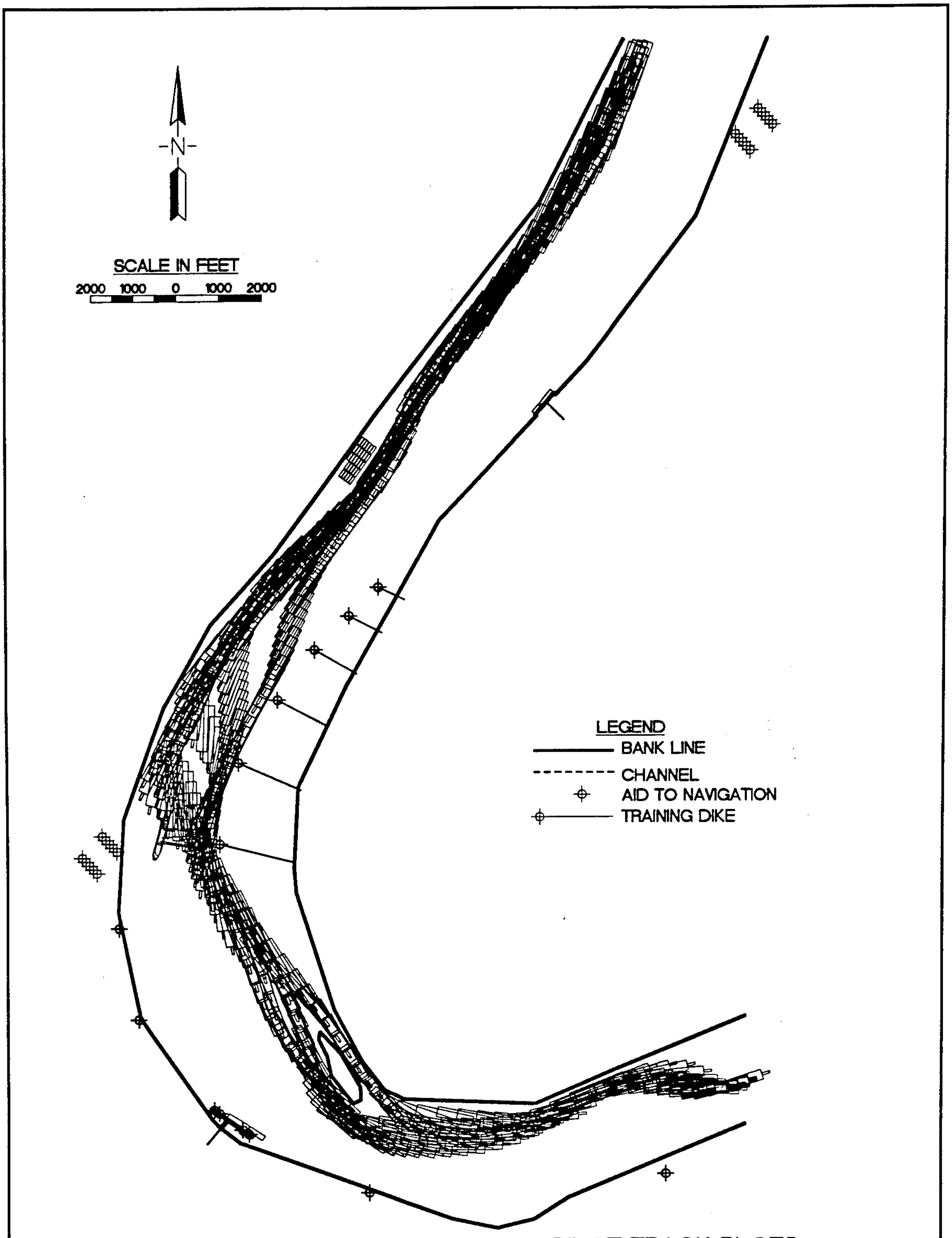

PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, UPSTREAM RUN
49-BARGE TOW, 1365' LONG X 245' WIDE
670,000-CFS FLOW
ALL RUNS

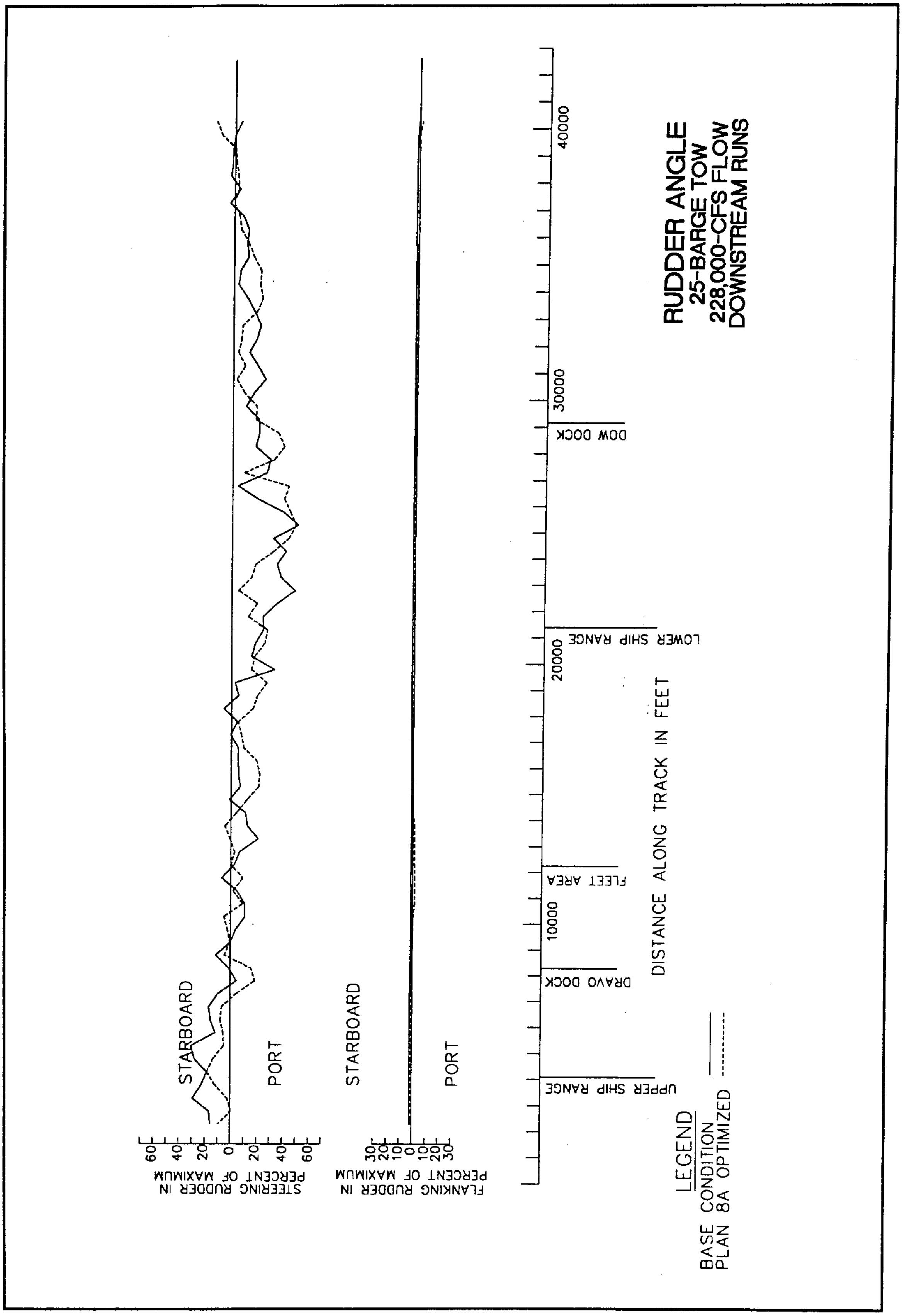

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
PILOT TRACK PLOTS
EXISTING CONDITION, DOWNSTREAM RUN
25-BARGE TOW, 975' LONG X 175' WIDE
1,500,000-CFS FLOW
ALL RUNS

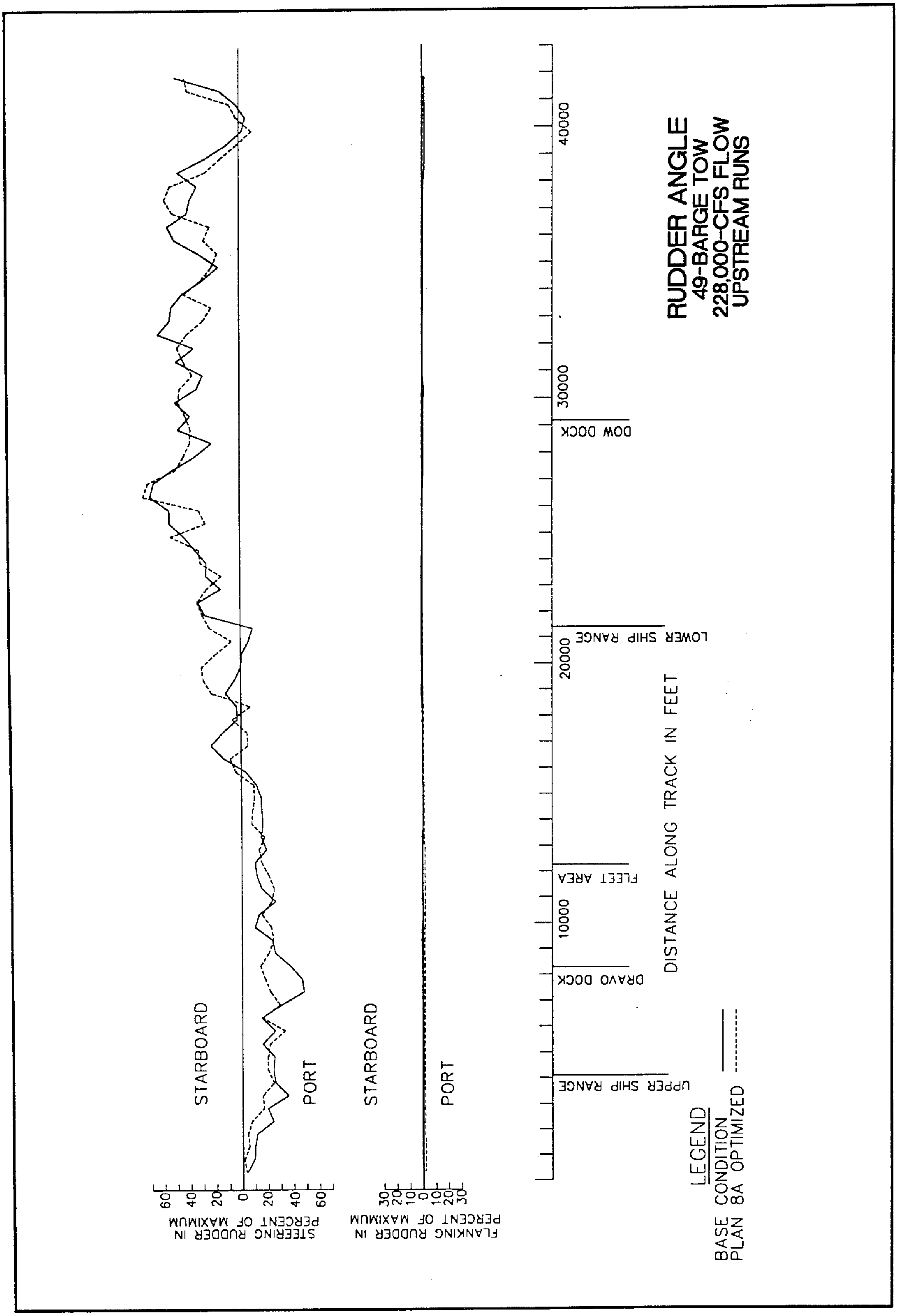

-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, DOWNSTREAM RUN
25-BARGE TOW, 975' LONG X 175' WIDE
1,500,000-CFS FLOW
ALL RUNS

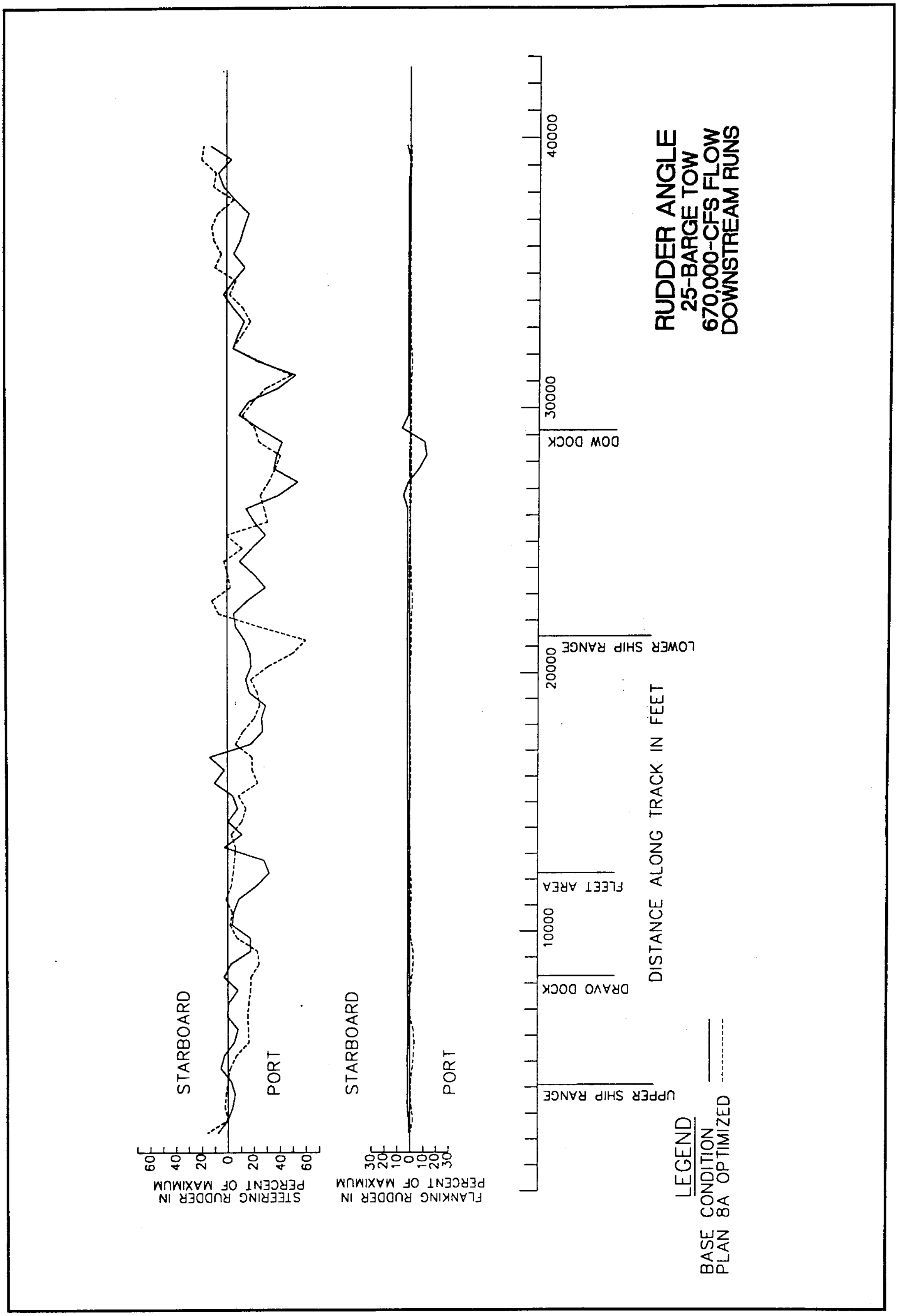


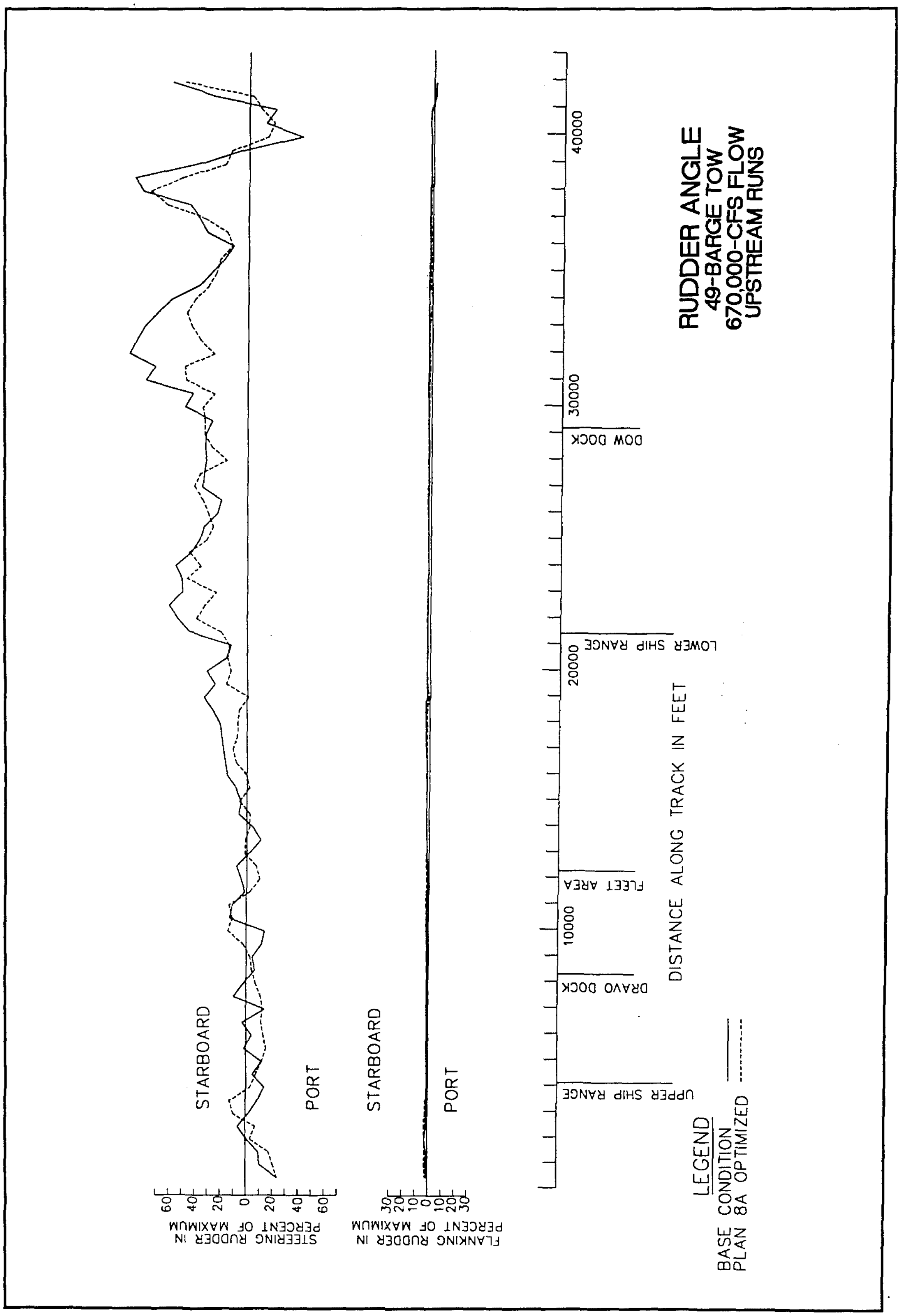

PILOT TRACK PLOTS
EXISTING CONDITION, UPSTREAM RUN
49-BARGE TOW, 1365' LONG X 245' WIDE
1,500,000-CFS FLOW
ALL RUNS


-N-
SCALE IN FEET
2000 1000 0 1000 2000
LEGEND
BANK LINE
CHANNEL
AID TO NAVIGATION
TRAINING DIKE
PILOT TRACK PLOTS
PLAN 8A OPTIMIZED, UPSTREAM RUN
49-BARGE TOW, 1365' LONG X 245' WIDE
1,500,000-CFS FLOW
ALL RUNS

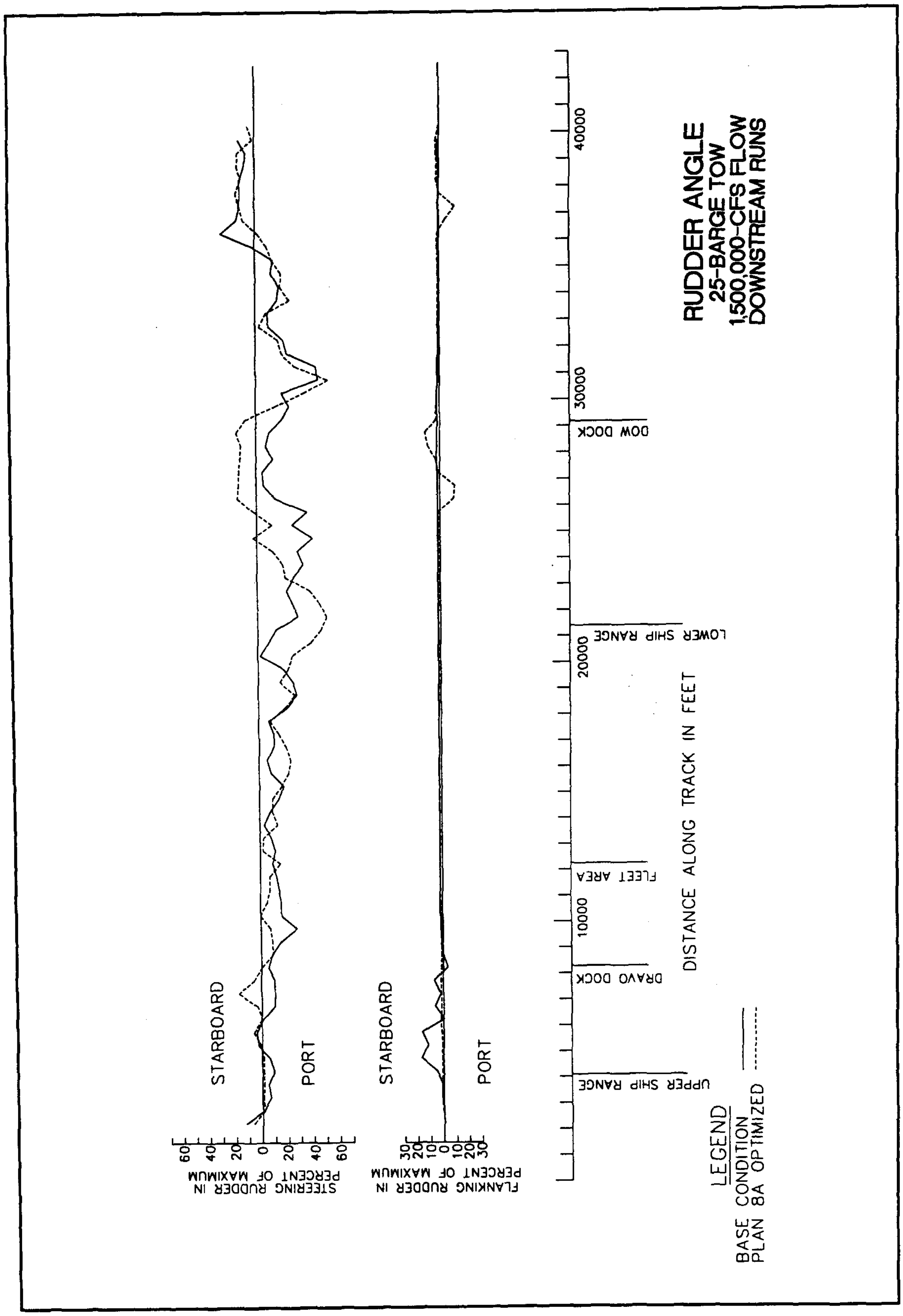

RUDDER ANGLE
25-BARGE TOW
228,000-CFS FLOW
DOWNSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


RUDDER ANGLE
49-BARGE TOW
228,000-CFS FLOW
UPSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
10000
20000
30000
40000
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED

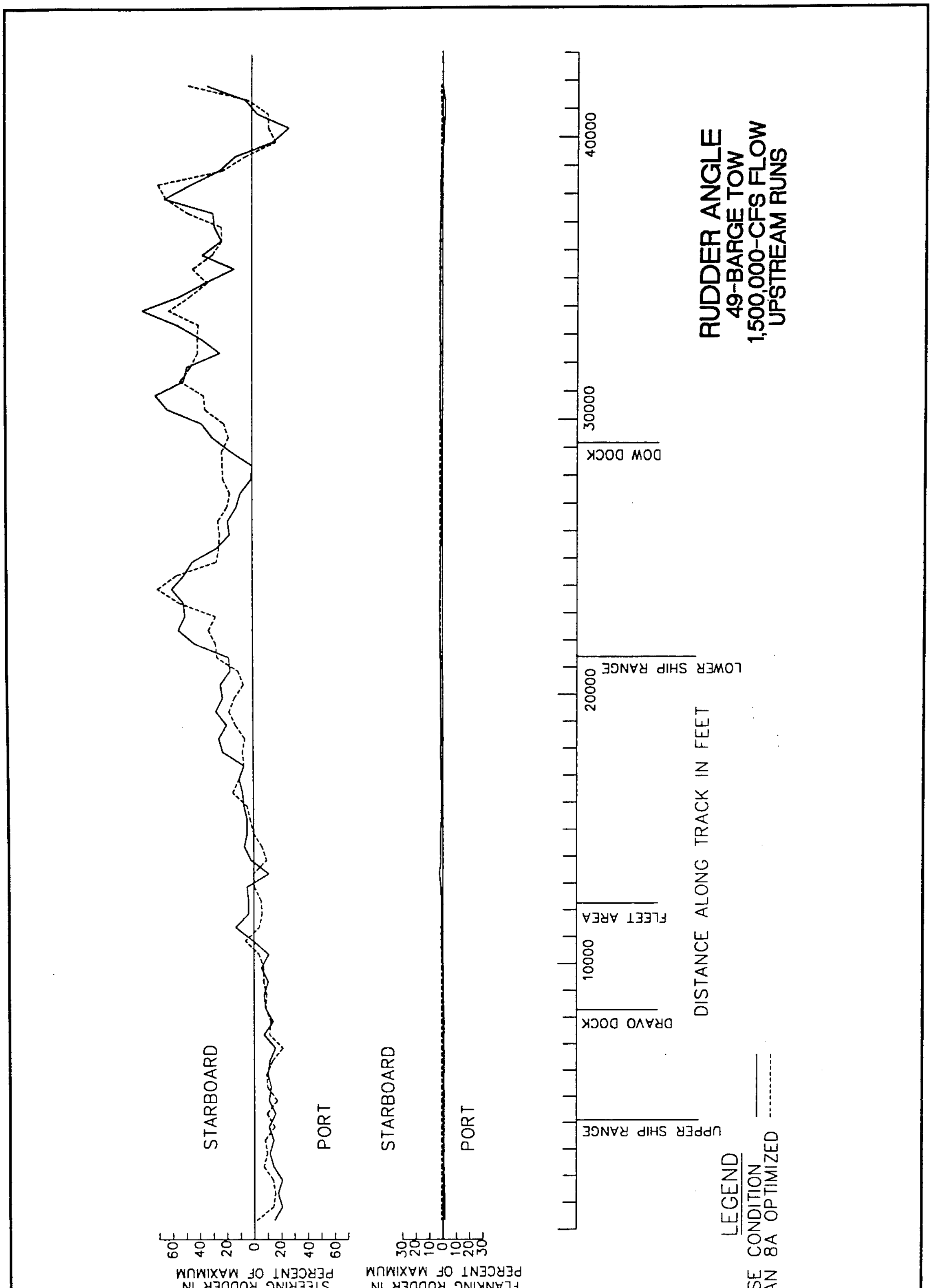

RUDDER ANGLE
25-BARGE TOW
670,000-CFS FLOW
DOWNSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED

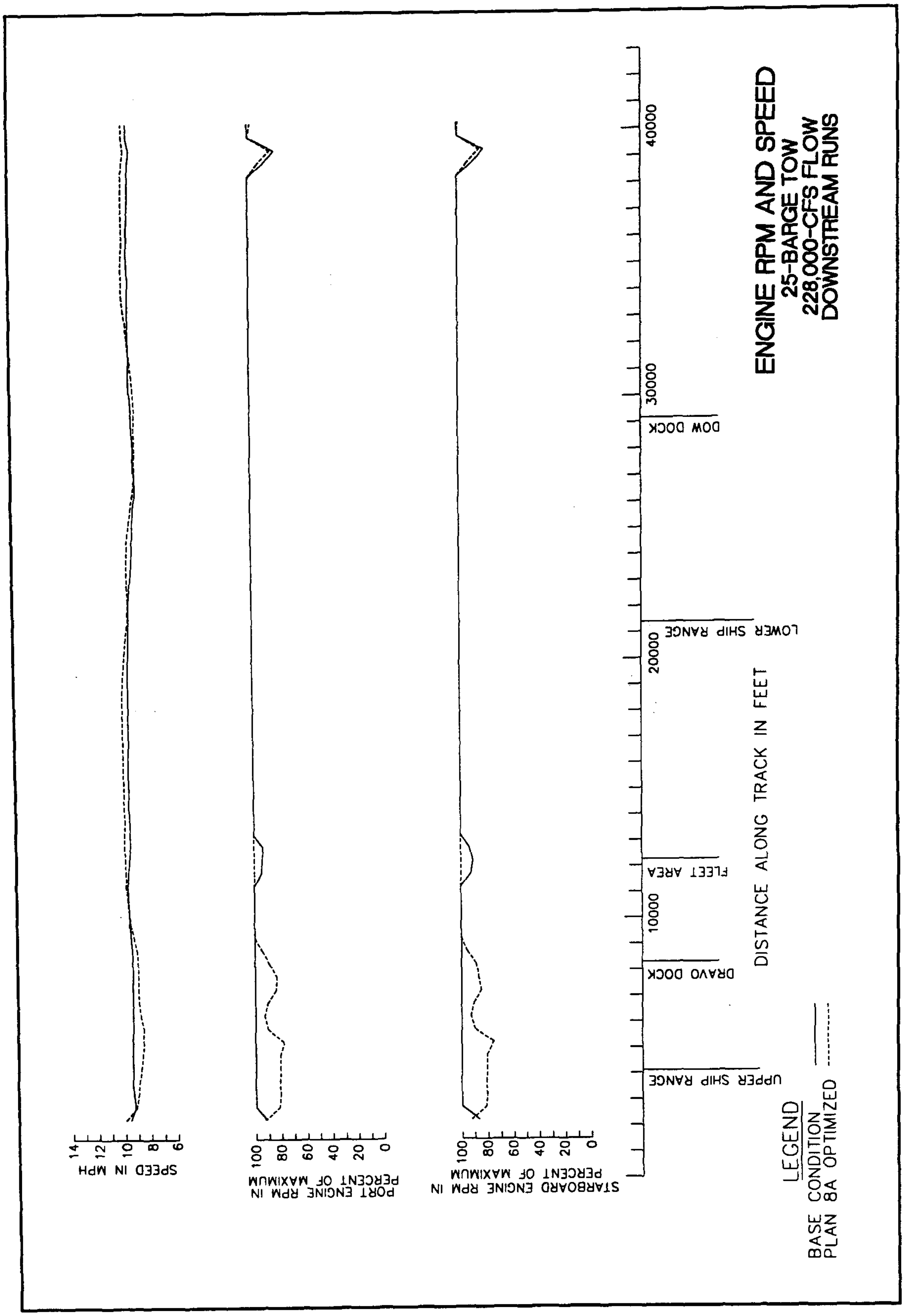


RUDDER ANGLE
49-BARGE TOW
670,000-CFS FLOW
UPSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED

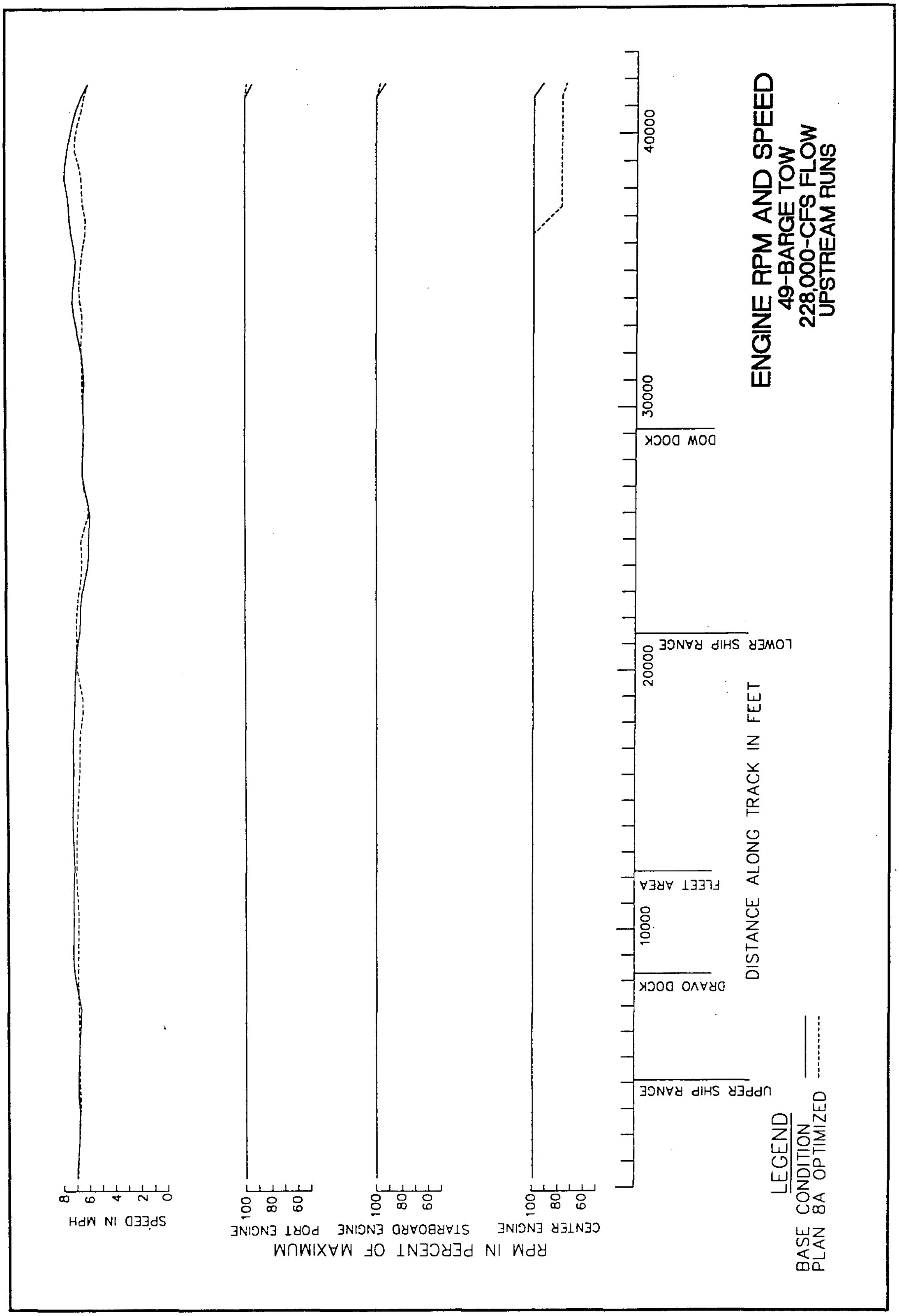


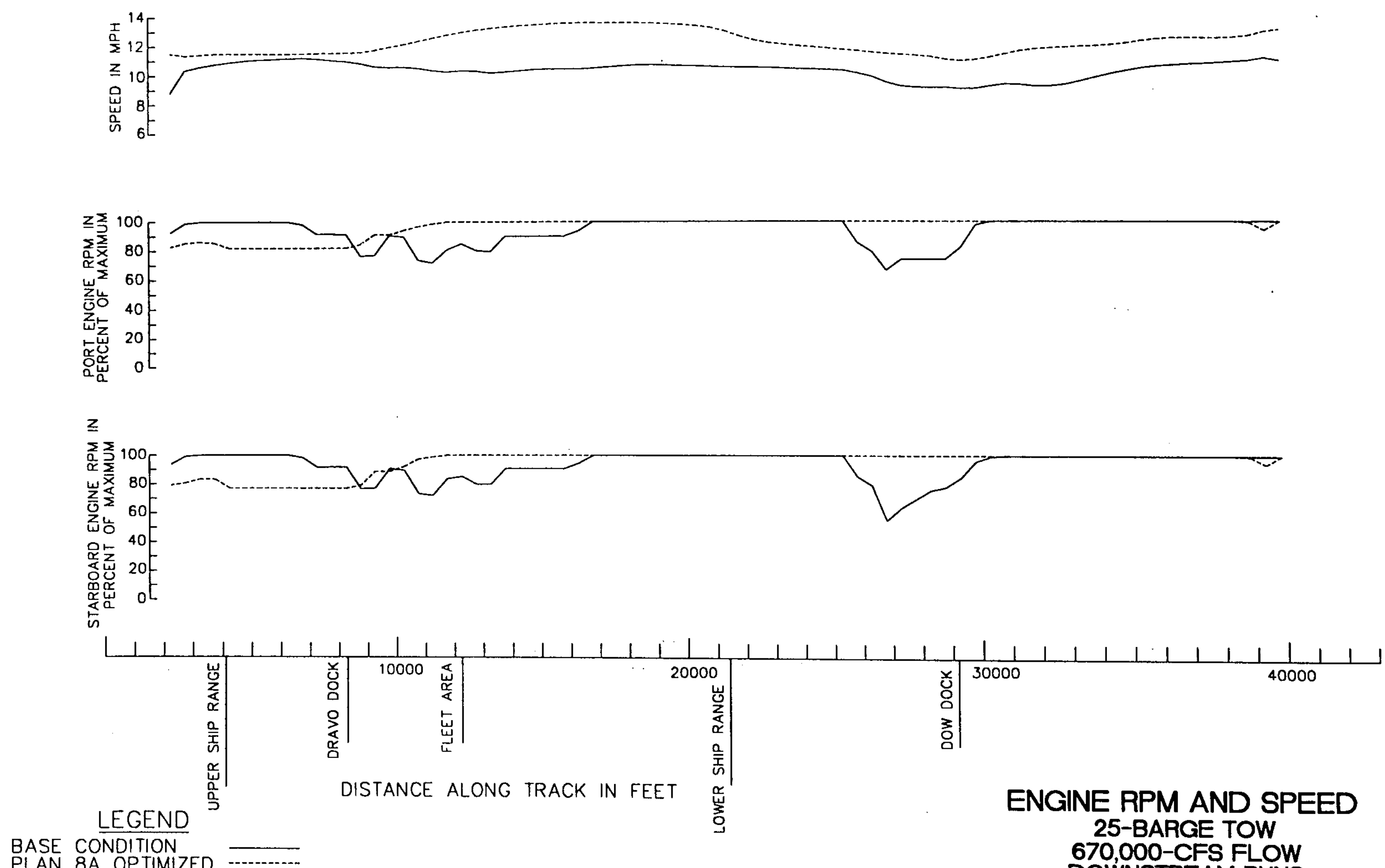
RUDDER ANGLE
25-BARGE TOW
1,500,000-CFS FLOW
DOWNSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
60 40 20 0 20 40 60
STARBOARD
PORT
FLANKING RUDDER IN PERCENT OF MAXIMUM
30 20 10 0 10 20 30
STARBOARD
PORT
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


RUDDER ANGLE
49-BARGE TOW
1,500,000-CFS FLOW
UPSTREAM RUNS
STEERING RUDDER IN PERCENT OF MAXIMUM
FLANKING RUDDER IN PERCENT OF MAXIMUM
STARBOARD
PORT
STARBOARD
PORT
60
40
20
0
20
40
60
30
20
10
0
10
20
30
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED



ENGINE RPM AND SPEED
25-BARGE TOW
228,000-CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
14 12 10 8 6
PORT ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


ENGINE RPM AND SPEED
49-BARGE TOW
228,000-CFS FLOW
UPSTREAM RUNS
DISTANCE ALONG TRACK IN FEET
10000
20000
30000
40000
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
SPEED IN MPH
8
6
4
2
0
PORT ENGINE
STARBOARD ENGINE
CENTER ENGINE
100
80
60
RPM IN PERCENT OF MAXIMUM
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED




**ENGINE RPM AND SPEED**
**25-BARGE TOW**
**670,000-CFS FLOW**
**DOWNSTREAM RUNS**

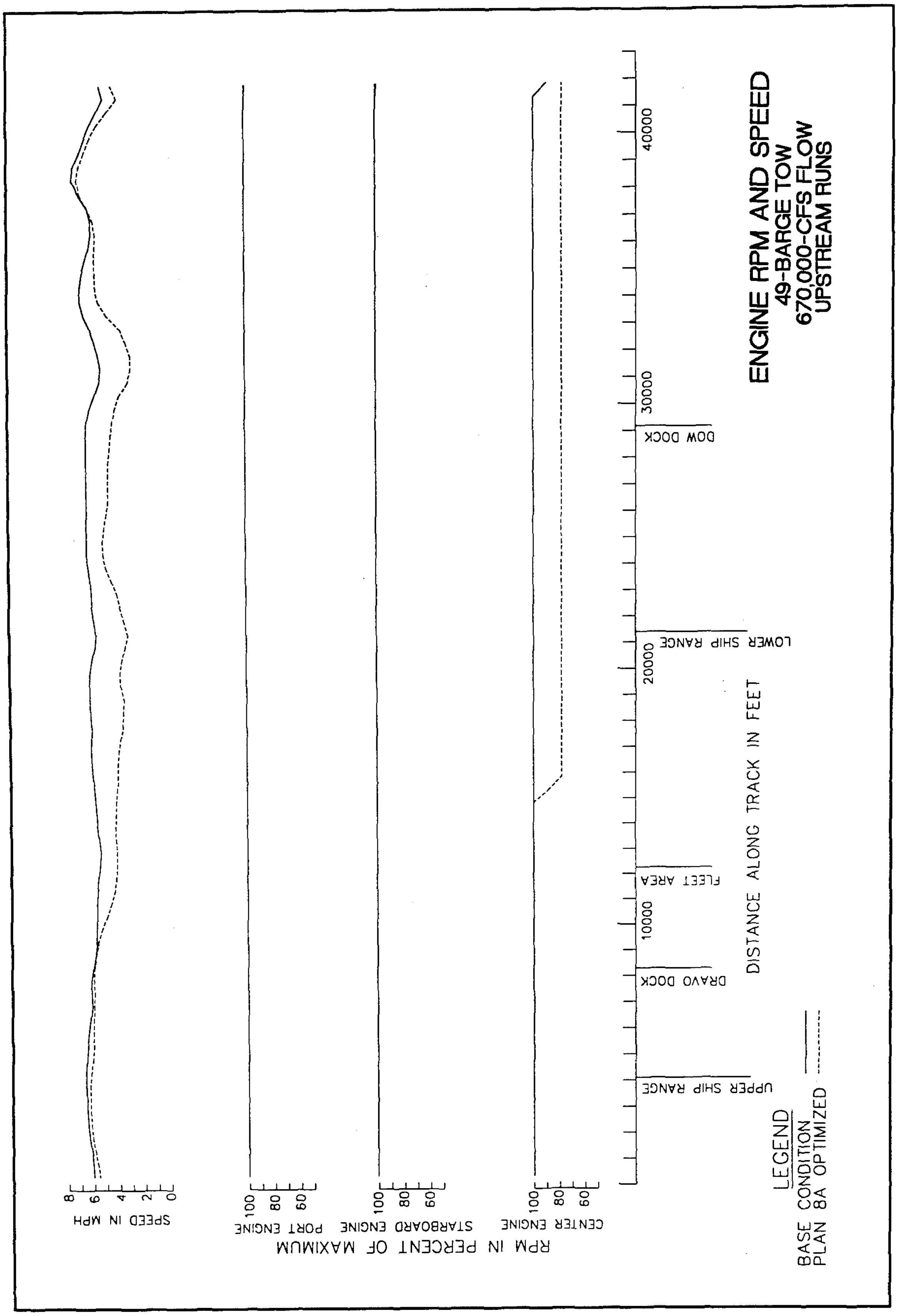
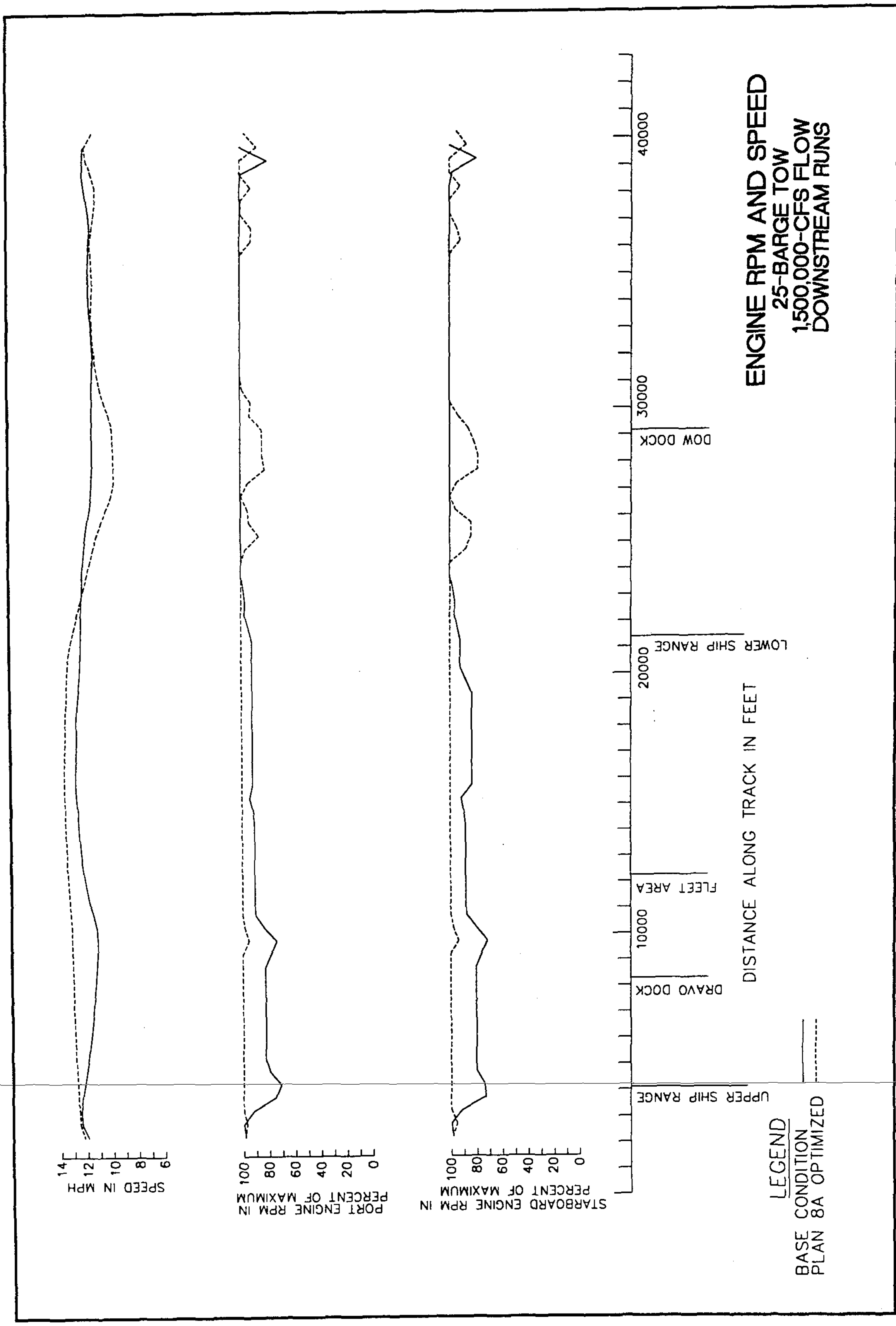
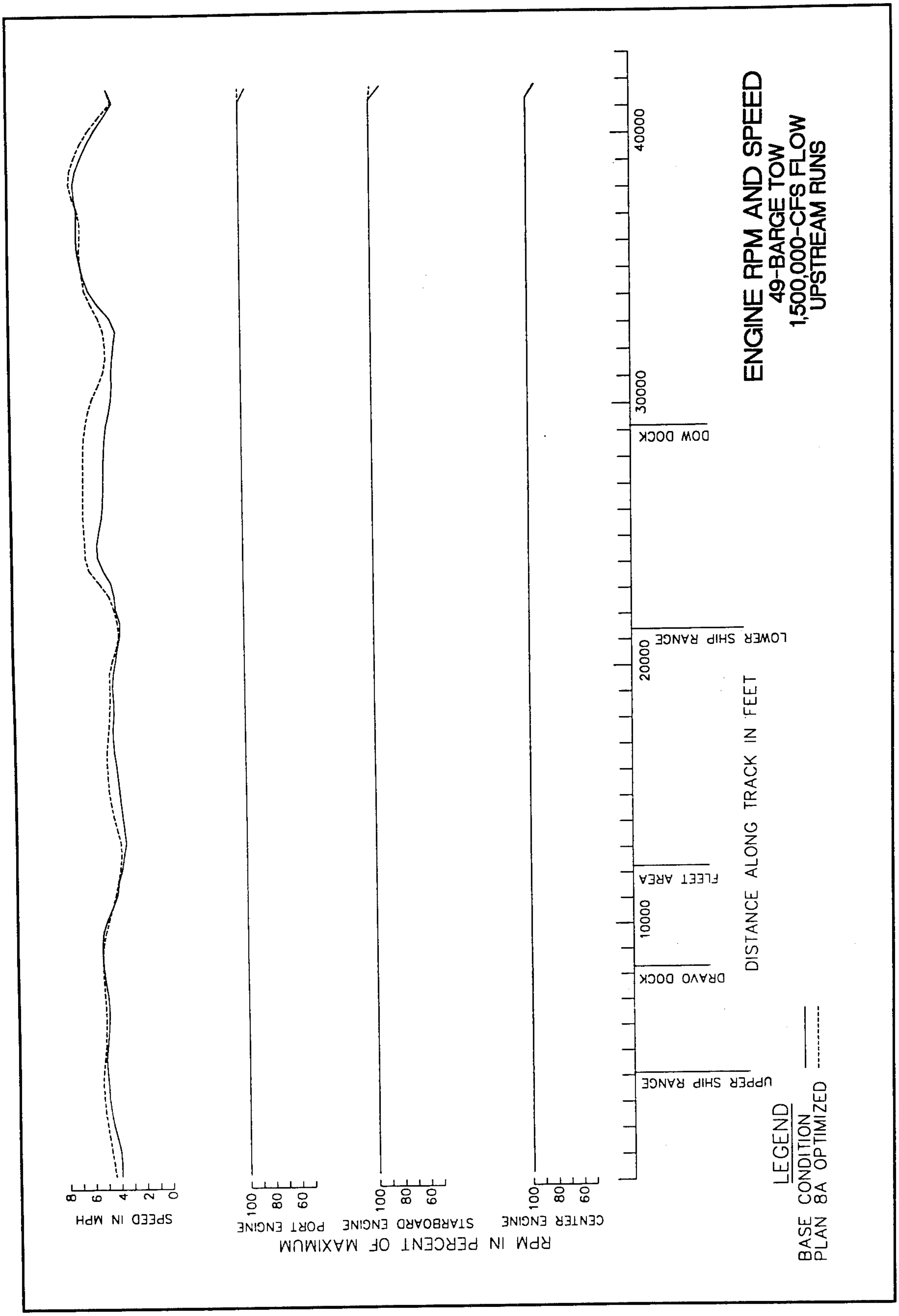

ENGINE RPM AND SPEED
49-BARGE TOW
670,000-CFS FLOW
UPSTREAM RUNS
SPEED IN MPH
8
6
4
2
0
RPM IN PERCENT OF MAXIMUM
PORT ENGINE
STARBOARD ENGINE
CENTER ENGINE
100
80
60
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED

Plate 110


ENGINE RPM AND SPEED
25-BARGE TOW
1,500,000-CFS FLOW
DOWNSTREAM RUNS
SPEED IN MPH
14 12 10 8 6
PORT ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
STARBOARD ENGINE RPM IN PERCENT OF MAXIMUM
100 80 60 40 20 0
UPPER SHIP RANGE
DRAVO DOCK
10000
FLEET AREA
20000
LOWER SHIP RANGE
DOW DOCK
30000
40000
DISTANCE ALONG TRACK IN FEET
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED


ENGINE RPM AND SPEED
49-BARGE TOW
1,500,000-CFS FLOW
UPSTREAM RUNS
LEGEND
BASE CONDITION
PLAN 8A OPTIMIZED
DISTANCE ALONG TRACK IN FEET
10000
20000
30000
40000
UPPER SHIP RANGE
DRAVO DOCK
FLEET AREA
LOWER SHIP RANGE
DOW DOCK
SPEED IN MPH
8
6
4
2
0
PORT ENGINE
STARBOARD ENGINE
CENTER ENGINE
100
80
60
RPM IN PERCENT OF MAXIMUM

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
March 1996

**3. REPORT TYPE AND DATES COVERED**
Report 2 of a series

**4. TITLE AND SUBTITLE**
Redeye Crossing Reach, Lower Mississippi River; Report 2: Navigation Conditions

**5. FUNDING NUMBERS**

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**8. PERFORMING ORGANIZATION REPORT NUMBER**
Technical Report HL-95-13

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
U.S. Army Engineer District, New Orleans
P.O. Box 60267
New Orleans, LA 70160-0267

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**
Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

Redeye Crossing, on the lower Mississippi River between River Miles 223 and 225, has tow traffic from 1 to 49 barges and oceangoing vessels up to 40-ft draft. The presently maintained channel requires approximately 3 million cubic yards of dredging annually to maintain the 40-ft-draft channel through the crossing. The proposed 45-ft-draft channel would require increased dredging without the use of channel training structures.

Proposals to construct a series of spur dikes along the left descending bank adjacent to the Redeye Crossing are being considered. The effects of these dikes on traffic in the crossing could not be determined except by the use of the U.S. Army Engineer Waterways Experiment Station (WES) ship/tow simulator. The plans as tested in the simulator were (a) existing channel conditions; (b) Plan 5A with dikes to maintain a 40-ft channel; and (c) Plan 8A with dikes to maintain a 45-ft channel. The vessels tested were (a) 2-barge tows; (b) 840- by 138-ft tankers; and (c) 25- and 49-barge tows. Pilots licensed to operate the particular vessels being considered in the Redeye Crossing area came to WES and performed transiting operations in the study reach with the different channel designs over a range of river discharge and stages.

The studies found that the dikes would have little effect on the deep-draft ships and the large tows. The small tows will have added difficulty in transits, especially going upstream, due to the increase of current speed in the deep-draft channel and the restriction of channel width in the crossing available to the small tows during low river stages.

**14. SUBJECT TERMS**

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|---|---|
| Maintenance dredging | Ship simulation |
| Mississippi River | Tow simulation |
| Navigation study | Training structures |
| Redeye Crossing | |

**15. NUMBER OF PAGES**
188

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | | |